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TEN YEARS OF SPACE RESEARCH IN THE USSR

M.K. Tikhonravov, B.V. Raushenbakh, G.A. Skuridin
and O.L. Vaysberg

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ABSTRACT: The first part of the paper contains a chronological account of the development of Soviet astronautics from the launching of the first satellite in 1957 until the present. The purposes of the satellites and their crews and performance are discussed. The second part of the paper covers various natural phenomena occuring at high altitudes and in space, and describes how Soviet spacecraft have provided additional knowledge about these phenomena. The text contains photographs of representative satellites from each series.

The ten years which have passed since the day when the first /643*
artificial Earth satellite was launched into space have been marked by a rapid development of spacecraft technology and astrophysics. A new era in human history began on October 4, 1957 - the era of space flight.

The first ideas regarding human exploration of space appeared in Russia at the turn of the century in the works of the great K. E. Tsiolkovskiy. His works, which have become generally known everywhere today, as well as the work of his successors, were naturally of a purely theoretical nature. It was only in the 1920's and 30's that articles dealing with rocket technology went beyond the field of theoreticians and popular science writers and became the subject of concentrated activity of scientists and engineers affiliated with scientific institutions and engineering organizations. The successes of the pre-war years were expanded and developed during the 1940's and 1950's. The leading scientist in the field of space technology and one of its organizers was Academician S. P. Korolev, who began his investigations more than 35 years ago. A large group of scientists and engineers worked together with S. P. Korolev, without whose valuable contribution the success of the entire venture would have been impossible.

We must not forget that in order for the exploration of space to begin, it was necessary to solve a great many scientific problems.

It was necessary to develop complete designs for the components of large-scale carrier rockets, capable of lifting enormous payloads, ensuring all the required margins of safety; to incorporate in their design the required aerodynamic features and characteristics which

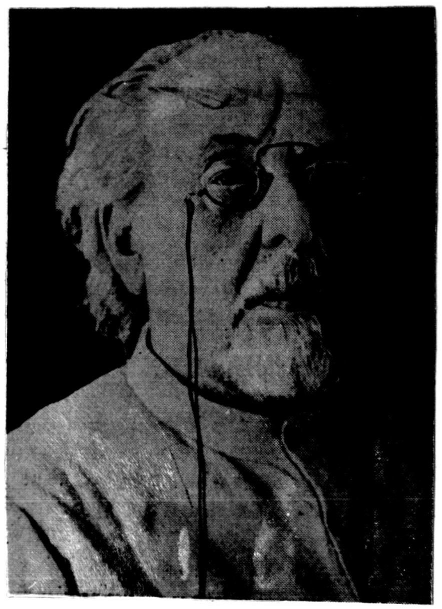
* Numbers in the margin indicate original pagination in the text.

would take account of possible elastic vibrations of the body of the rocket and the oscillation of the liquid volumes in the fuel chambers; it was necessary to determine the most advantageous conditions for separating the rocket into stages and studying the optimum flight projectory.

It was necessary to develop powerful liquid fuel rocket motors with a high specific thrust, ensure reliable cooling of the combustion chamber and jet, and guarantee reliability of operation of the motors, solving the problem of doing away with dangerous high-frequency vibrations in the motor which sometimes occur due to irregularity in the burning process, etc.

It was necessary to develop a system of automatic control for the flight of the rocket, which would follow a given flight trajectory with a high degree of accuracy, and would control not only the position of the rocket in space but the operation of the motors as well. The problem of building such a system was complicated by the fact that working it out required consideration of the elastic vibrations of the body of the rocket and the oscillation of the fuel in the chambers.

It was necessary to build a launching complex on the ground, without which it would have been impossible to launch spacecraft. /644



K.E. Tsiolkovskiy

If we are talking about the design of the space vehicles themselves (artificial Earth satellites and unmanned interplanetary stations), their design required the solution of no less complicated scientific and technical problems:

1. The design of mechanisms able to operate under conditions of weightlessness and the high vacuum of interplanetary space while maintanining the required temperature; the solution of problems regarding energy sources on board, the development of systems of automatic control on board, etc.

2. The design of control systems for spacecraft, able to orient them as desired and to place them in a given position, even changing the flight trajectory if necessary. Unlike the control systems of the carrier rockets, the orienting systems frequently had to operate continually for many months.

3. The design of a ground radio complex for measurements of

the trajectories, communications, and control of the flight of the spacecraft.

4. The design of the required protection for devices being returned to Earth, against the high temperatures which are developed upon their reentry into the atmosphere at cosmic speeds.

5. A number of medical and biological problems must be solved as far as manned spacecraft are concerned in order to make it possible for cosmonauts to maintain their efficiency at the required level, both on board the spacecraft and when they leave it to walk in space.

The correct answers to all the problems that arise can only be solved by skilled groups of scientists and designers working with theoretical, experimental and engineering problems of the most diverse nature. It is difficult to overestimate the role which Soviet scientific institutes and engineering bureaus played; the active participation of the most skilled scientists in our country was necessary.Many significant aspects of this work were coordinated by the Academy of Sciences of the USSR.

S.P. Korolev

During the last ten years, extremely interesting scientific investigations have been carried out in space by the United States, France, England, Canada, Italy and other countries. Artificial Earth satellites have been built for communications and uninterrupted meteorological observation. The United States, with the aid of manned vehicles, carried out such important experiments in space technology as (for example) rendezvous and docking in orbit. In addition, the spacecraft launched by the United States made flights to Mars and Venus and provided important data on the investigation of the Moon. /645

The present paper is devoted to a brief description of the development of spacecraft technology in the USSR and all of the scientific investigations of space which were carried out with the aid of artificial Earth satellites and spacecraft.

The achievements of spacecraft technology in the USSR have been employed for solving the most pressing problems of contemporary science. In this respect, broad scientific and engineering undertakings have been carried out in the USSR, of which the most important achievement was the launching into orbit around the Earth on October 4, 1957 of the first artificial Earth satellite in history.

The first artificial Earth satellite was a sphere 58 cm in diameter, weighing 83.6 kg. It was equipped with a system of heat regulation, a device for measuring temperature, radio transmitters and power sources. There were two antennas, 2.4 m long, and two other antennas located perpendicular to the others, 2.9 m long. The purposes of building the first artificial Earth satellite were: the testing of scientific and engineering methods used in designing carrier rockets and satellites, the investigation of the passage of radio waves through the ionosphere, the development of a thermal regime in the satellite, and an experimental study of the density of the upper layers of the atmosphere as reflected in the slowing down of the satellite. The satellite lasted for 92 days and made about 1400 revolutions around the Earth.

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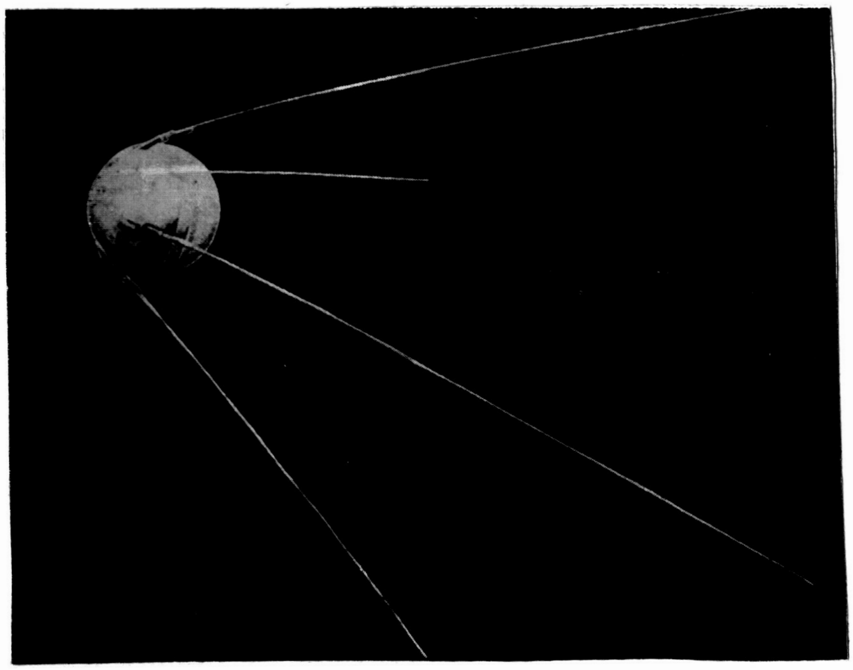
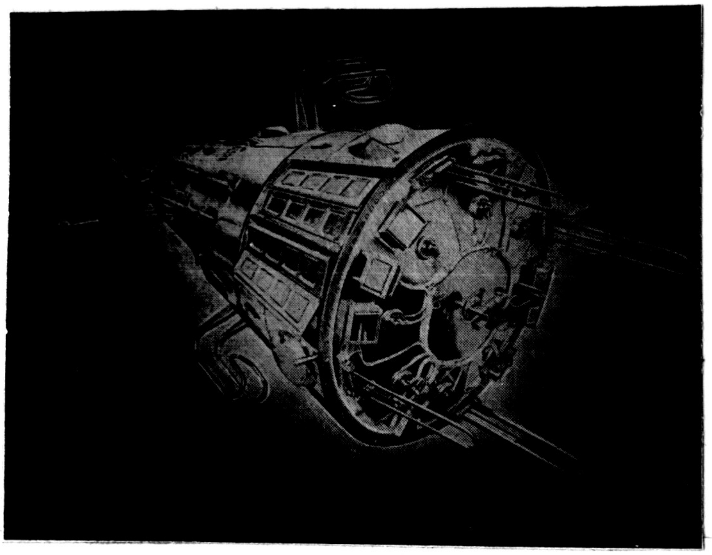


First Artificial Earth Satellite

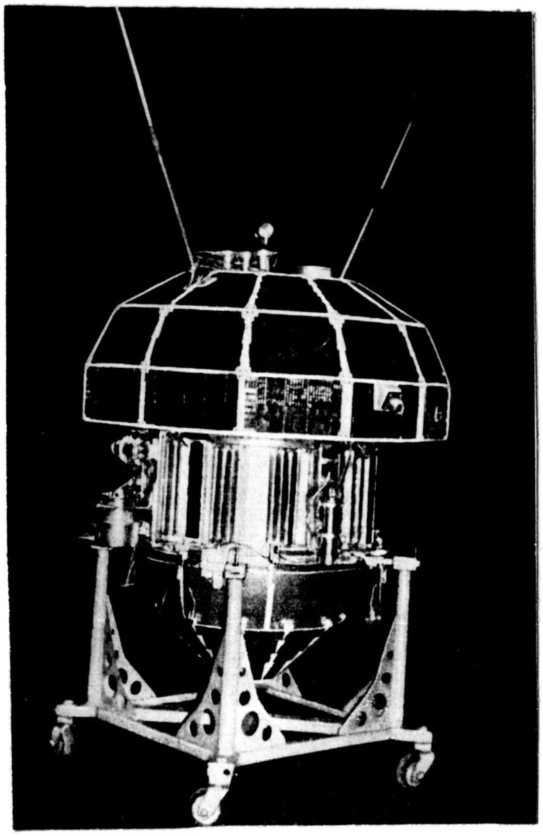
The second artificial Earth satellite was launched in the Soviet Union on November 3, 1957. It contained apparatus for studying solar ultraviolet and x-radiation, as well as cosmic rays. In order to study life processes under space flight conditions, the satellite carried a dog named "Layka". Transmitters attached to the body of the animal recorded pulse rate and respiration, blood pressure, and several other biological parameters. In this way, it was possible for the first time to study (on board a satellite) the long-term /647 /648 effects of weightlessness on a living organism. The second satellite did not separate from the last stage of the carrier rocket.



Third Artificial Earth Satellite.

On May 15, 1958 the third artificial Earth satellite was launched into orbit in the Soviet Union. It carried a number of different devices with which it was possible to carry out studies of the upper layers of the atmosphere and the space around the Earth. It should be mentioned that an experimental solar battery was used on board the third satellite to power the "Mayak" radio transmitter. The /649 weight of the third satellite was 1327 kg; it made more than 10,000 revolutions around the Earth and lasted until April 6, 1960.

On March 16, 1962 regular launching of artificial EArth satellites in the "Cosmos" series began in the Soviet Union, for further investigations of the cosmic space around the Earth in conjunction with the program of the Academy of Sciences of the USSR published on March 16, 1962. The artificial Earth satellites in the "Cosmos" series were equipped with diverse scientific apparatus. Their design made it possible for them to carry out prolonged studies of solar activity and the condition of the upper atmosphere and ionosphere; to investigate the radiation conditions in the vicinity of the Earth; to record meteorological information from all over the globe; to measure the magnetic field in space; to carry out tests of a number of new systems of devices on board and return them to Earth; to carry out medical and biological investigations; and to carry out studies related to the flight of spacescraft, such as a study of the effects of meteoritic substances, estimation of radiation danger, etc.



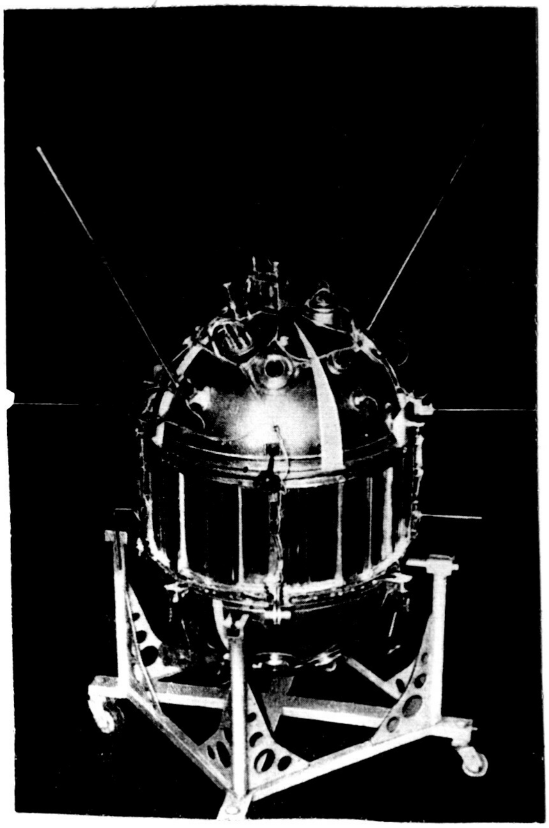
"Cosmos" Series Artificial Earth Satellite
for Studying Low Energy Particles.

The design and construction of the artificial Earth satellites in the "Cosmos" series is a very important step in the study of the physics of space, as a result of which Soviet scientists obtained a number of exciting results.

On November 1, 1963 and April 16, 1964, the spacecraft "Polet-1" and "Polet-2" were placed in orbit. They carried special devices and motor systems for carrying out maneuvers in space.

The further development of space exploration placed before the designers the problems of designing a number of special devices for more detailed investigation of the physical processes taking place in space and obtaining simultaneous measurements at different points in space. The solution of this problem called for the building of a completely new satellite design, launched simultaneously by means of one carrier rocket into different orbits. Satellites of this type were included in the space system called "Electron". This system consisted of two satellites launched into different orbits, one with /650
an apogee of about 7000 km and the other with an apogee of about 68,000 km.

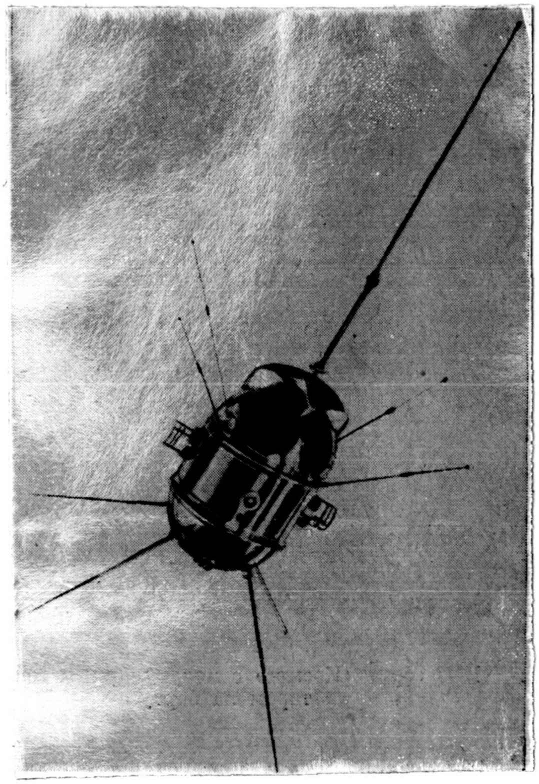
The first launching of the "Electron" space system took place on January 30, 1964 and the second took place on July 11 of the same year. The separation of the spacecraft "Electron-1" and "Electron-3" took place during the active portion of the flight. The last stages of the carrier rocket carried the stations "Electron-2" and



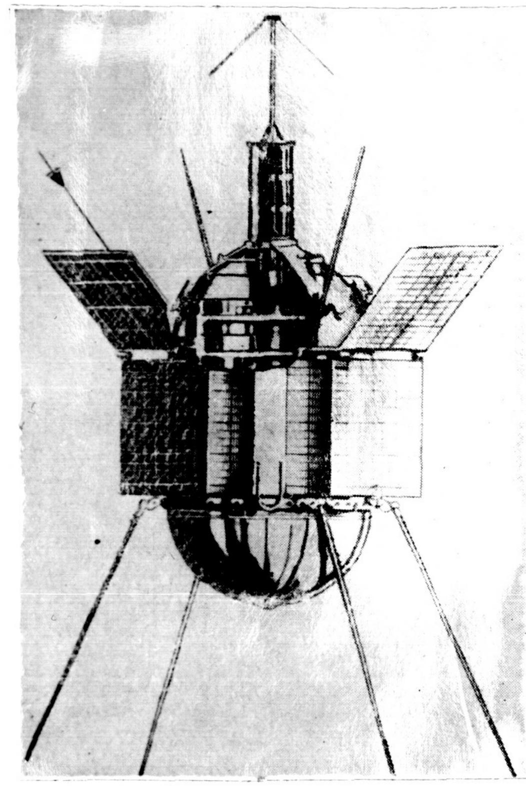
"Cosmos" Series Artificial Earth Satellite
for Studying the Ionosphere.

"Electron-4" into other, more elongated orbits. This made it possible to carry out a wide range of measurements required for investigations in the space around the Earth as well as for getting an idea of the nature of the radiation field of the Earth and the dynamics of the physical processes related to its formation.

The "Electron" satellites also carried out measurements of the magnetic field of the Earth, radiation, solar x-radiation, and the



"Cosmos" Series Artificial Earth Satellite for Measuring the Magnetic Field of the Earth.



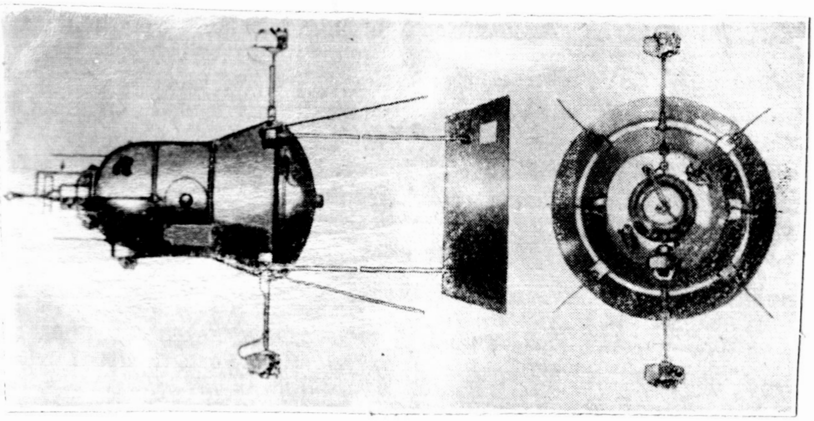
"Cosmos" Series Artificial Earth Satellite with a Molecular Generator on Board.

ionic composition of the atmosphere.

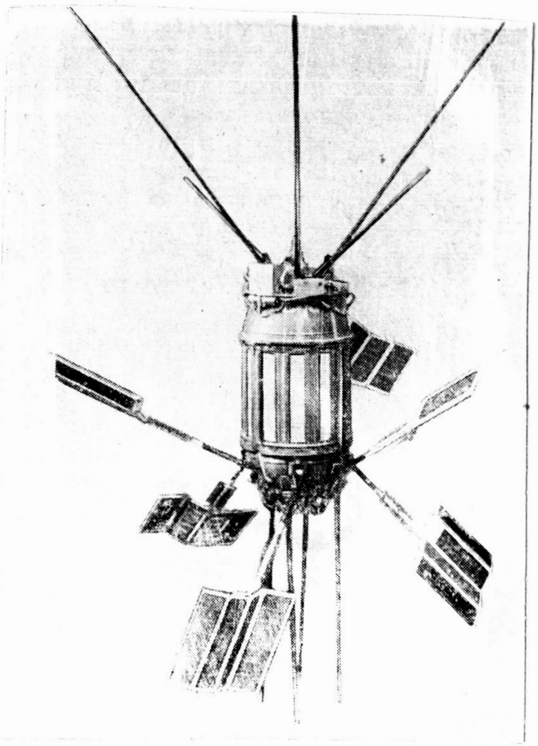
The study of the cosmic rays is of particular interest from different points of view, especially for investigation of those properties of elementary particles which can be understood only when sufficiently high energies are reached.

A study of the nature of the most elementary particles of cosmic rays with high and ultra-high energies (their composition and energy spectrum, the chemical composition of very heavy nuclei, the electron components and γ-quanta of high-energy elementary cosmic rays) helps us to get an idea of the mechanism of their creation and the processes involved in their interaction with galactic and interplanetary media; in other words, to add cosmic rays to the arsenal of active methods of contemporary astrophysics. /651

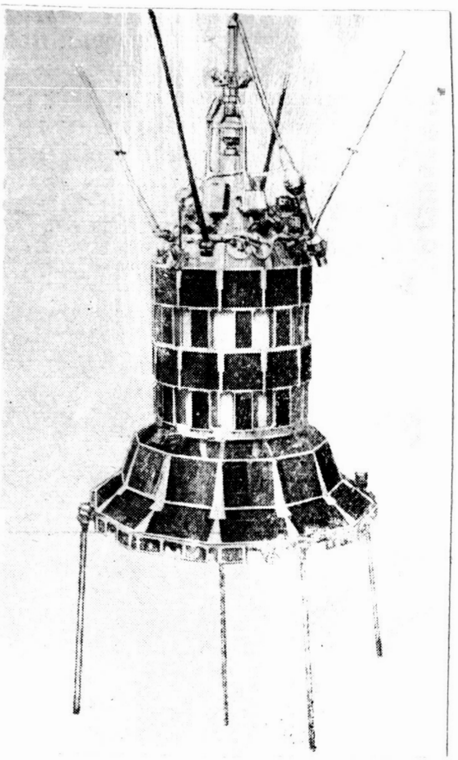
A knowledge of the composition and energy spectrum of elementary particles with both high and ultra-high energies is also required for solving a number of problems related to the investigation of the mechanism of the formation of secondary high-energy particles which occur in the atmosphere as a result of the interaction of ele-



Optical Satellite in the "Cosmos" Series.

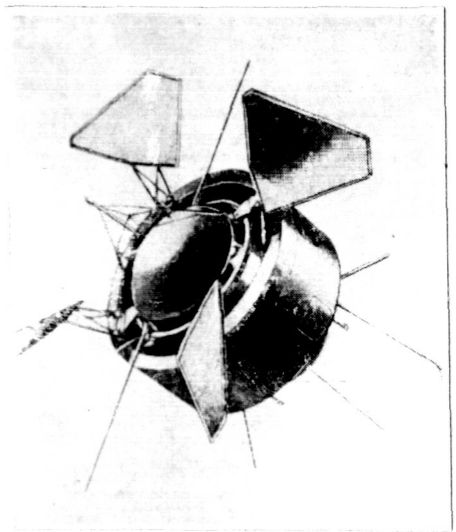


"Electron-1" Space Station.



"Electron-2" Space Station.

mentary particles with the nuclei of atoms of air. In recent years, a tendency has developed to record the quantitative characteristics of this interaction and to develop methods which ensure a sufficiently unambiguous interpretation of the experimental data. In the Soviet Union, this direction of research became more developed after a new method of measuring the energy of individual particles was discovered (the method of the ionization calorimeter) and ways were found to combine the ionization calorimeter with different means for observing the image of the interaction of elementary particles with atomic nuclei (the Wilson chamber, nuclear emulsions, spark chambers). The tracks left by particles of high energy cosmic rays are very small, while their intensity decreases rapidly with increased energy. In order to study such particles, we need apparatus of large size and measurements lasting a long period of time, located at a great height because the primary cosmic rays are strongly slowed down in the atmosphere. An analysis of the possibilities for using cosmic rays to explain many problems in the physics of high energy /652 particles led to a decision to combine a number of experiments on atmsopheric phenomena aboard heavy Earth satellites which could be placed at a great height and at a great distance. This equipment would include the ionization calorimeter, as well as additional apparatus which would make it possible to investigate the properties of particles over a wide energy range from 10^{10} to 10^{14} eV. The first step in this direction was the scientific space station in the "Proton" series.



Space Station in "Proton" Series.

On July 16, 1965 a powerful new carrier rocket launched the heavy scientific space station "Proton-1" into orbit around the Earth; it carried a heavy payload. The "Proton-1" station was equipped with scientific apparatus for studying cosmic particles with both high and ultra-high energies. On November 2, 1965 and July 6, 1966 two space stations ("Proton-2" and "Proton-3") were launched into orbit. The spacecraft in the "Proton" series were equipped with a unique apparatus for measuring solar cosmic radiation, determining the chemical composition of the elementary cosmic radiation in the energy range from 10^{10} to 10^{14} eV, detecting the inelastic interaction of cosmic particles of high and ultra-high energies with matter, measuring the intensity and the energy spectrum of the γ-radiation of galactic origin, determining the absolute intensity and energy spectrum of electrons of galactic origin, and searching for new fundamental particles with a fractional charge (quarks"). The launching of the "Proton" stations was a new step in the investigation of the physics of cosmic rays.

Artificial Earth satellites have opened up broad possibilites for solving many problems which have immediate significance for the national economy. The building of a global system of space communication as well as meteorological systems have acquired enormous significance at the present time for fulfilling the practical needs of mankind.

On April 23, 1965 the communications satellite "Molniya-1" was launched from the Soviet Union into a high elliptical orbit. The principal purpose of the communications satellites is to carry out transmission of television programs and long distance two-way multichannel telephone, phototelegraph and telegraph communications. The purpose of the launchings of the first satellite "Molniya-1" and the ones that followed it (October 14, 1965, April 25, 1966, October 20, 1966 and May 25, 1967) was the development and further refinement of radio and television communication systems using artificial Earth satellites as active relay stations, and experimental use of such systems. The apogee of the orbit of all the "Molniya-1" satellites was on the order of 40,000 km and their period of rotation was about 12 hours.

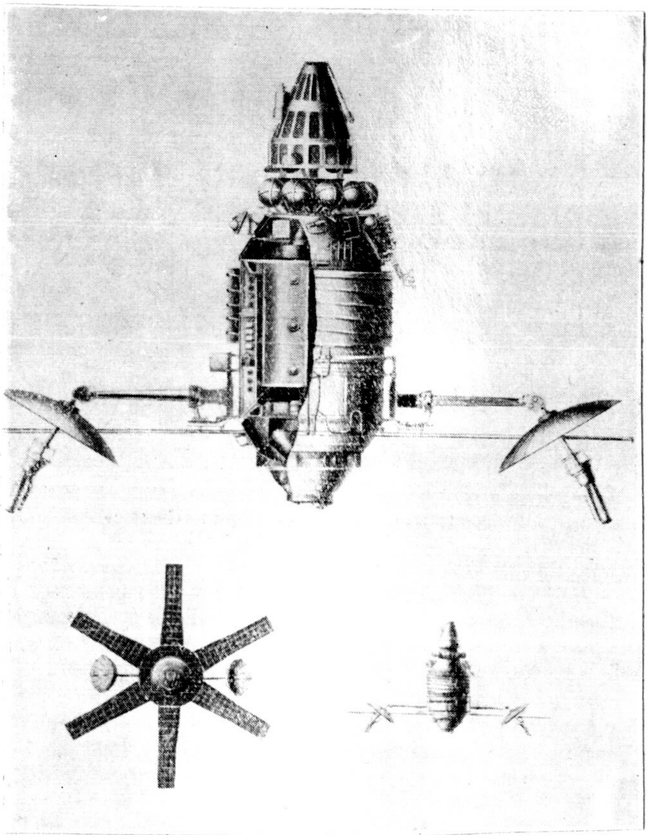
Using the "Molniya-1" satellites, long distance radio and television communications were successfully established between the center of the European territory of the USSR (i.e., Moscow) and the Far /653
East, and experimental transmission of color television *via* space between the Soviet Union and France based on the "Secam" system. The launching of two or more satellites into different orbits makes it possible to ensure 24-hour communication practically between any two points, even those extremely far apart, within the enormous territory of the Soviet Union.

On May 18, 1966, using a television camera with adjustable lens and light filters of different densities, mounted on the body of one of the "Molniya-1" satellites, photographs were made of the Earth from a distance of almost 40,000 km. Pictures from such a great height make it possible to track large cloud systems over the Northern Hemisphere. Hence, observations using "Molniya-1" communication satellites can be used as aids to weather forecasting.

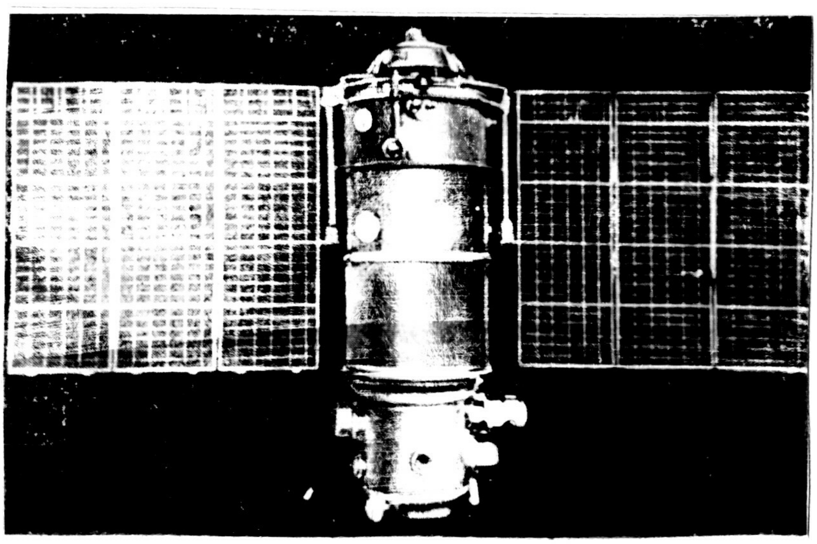
The creation of an experimental long-distance radio and television communication line by means of the "Molniya-1" satellites opens up tremendous possibilities for the use of space technology for the immediate needs of the population and for the national economy of our country.

The artificial Earth satellite "Cosmos-122" which was launched /654
into orbit on June 25, 1966 provided a rich supply of meteorological information. It transmitted to Earth, television pictures of clouds as well as the snow and ice covers of the Earth's surface. Individual pictures were assembled to form a picture of the cloud cover of the Earth, which made it possible to determine the nature of the circulation of air masses, their velocity and direction, and the distribution of fronts dividing air masses with different properties. The "Cosmos-122" satellite used infrared equipment to take pictures at night.

In addition to taking pictures of the cloud formations of the Earth, the "Cosmos-122" satellite carried an actinometric apparatus for obtaining data regarding the radiation balance of the Earth-



"Molniya-1" Communications Satellite.



"Cosmos" Series Meteorological Satellite.

atmosphere system. Measurements were made of the intensity of the radiation coming from the earth[1]. The "Cosmos-122" satellite made it possible to collect meteorological data for four months.

A special network of ground stations has been developed in our country for analyzing the information received from the satellites for use in forecasting within several hours.

On February 28, the meteorological satellite "Cosmos-144" was launched into orbit around the Earth. The artificial meteorological satellite "Cosmos-156" was placed in a circular orbit on April 27, 1967; the initial plane of the orbit was shifted relative to the plane of the satellite "Cosmos-144" by 95°. These satellites form the experimental system called "Meteor".

The mutual positions of the orbits of these two satellites were chosen so that they could take meteorological observations over all parts of the Earth at intervals of about six hours. A system consisting of two satellites makes it possible to obtain (during a period of 24 hours) information regarding half the surface of the Earth.

The "Meteor" system is operating satisfactorily, at the present time, transmitting valuable information for weather forecasting. /655

The first experimental systems of communication satellites and meteorological satellites show what kind of possibilities exist for the practical use of space in the interest of the national economy.

After the launching of the first artificial satellites, a new stage began in the development of space technology - the making of interplanetary flights. As a result of the dedicated labor of Soviet scientists and engineers, an interplanetary rocket was built which could reach (at the end of the active portion of its flight) a velocity equal to 11.2 km/sec. Voyages to the Earth's nearest neighbor in space, the Moon, and to the planets in the Solar System became a problem of immense scientific and technological difficulty. It was first of all necessary to make computations to find the optimum trajectories for flights with the maximum payload.

Two flight schemes were developed in the Soviet Union: flight from the Earth to the Moon without correction of the trajectory, and a flight from a parking orbit for artificial Earth satellites, followed by subsequent trajectory correction. Both systems required the design of highly accurate control systems for the rocket flight

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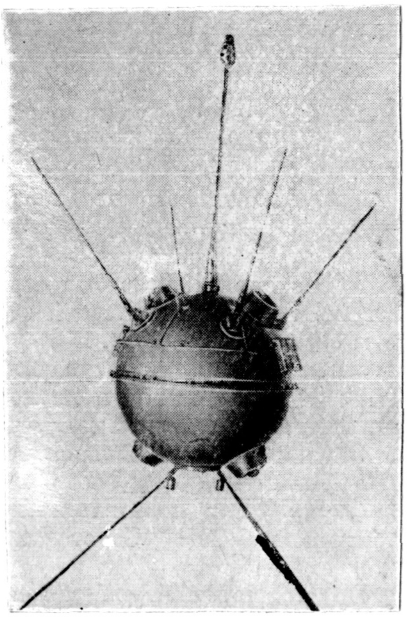
[1] The electronic devices, which oriented the meteorological satellite, were first tested on board the artificial satellite "Cosmos-23".

during the active portion and the development of on-board complexes for controlling the spacecraft in flight, including correcting devices, orientation systems, and radio systems which ensure communication over many hundreds of thousands of kilometers (and on flights to the planets, even hundreds of millions of kilometers).



Unmanned Interplanetary Station "Luna-1".

Flights to the Moon and planets are possible at certain astronomical periods. The plane of the orbit of the Moon is inclined at an angle of 18° to the plane of the Earth's equator. This means that in moving along the orbit, the declination of the Moon (i.e., the angle which a line from the center of the Earth to the Moon forms with the plane of the Earth's equator) changes from +18 to -18°. At the same time, launchings from the territory of the Soviet Union must be made when the Moon is located near that point in its orbit which has the minimum declination, i.e., -18°. In this case, during the acceleration portion of its flight the rocket will move at the maximum angle to the Earth's surface and its loss of speed owing to the Earth's attraction will be minimal. This ensures delivery of the maximum payload to the Moon. When the spacecraft hits the Moon, it must be located above the horizon in order to ensure direct radio communication with the rocket. The best time for this is when the Moon is located near the point of superior culmination, i.e., its altitude above the horizon must be maximum.

On the basis of all this, the optimum parameters for launching trajectory and launching time are selected for a given launching site.

On January 2, 1959 the first spacecraft was launched in the /656
direction of the Moon, carrying the unmanned station "Luna-1". The last stage of the rocket weighed 1472 kg. An unmanned station weighing 361.3 kg separated from it during the flight in order to ensure operation of the antennas and magnetometer. The separation of the station from the rocket also helped stabilize the thermal regime aboard it.

The last stage of the carrier rocket carried a special apparatus for creating an artificial sodium comet. The artificial comet was produced on January 3 and observed by many astronomical observatories.

The unmanned interplanetary station "Luna-1" reached the immediate vicinity of the Moon, coming to within a distance of 7.5 thousand km from its surface. It then entered orbit as a satellite of the Sun and thus became the first artificial planet in the Solar System.

The devices aboard the "Luna-1" station made it possible to investigate the intensity of the radiation in the vicinity of the Earth and the intensity of cosmic radiation; magnetic measurements were carried out at great distances from the Earth. During the flight, there was observed for the first time, a deviation of the strength of the magnetic field at a distance of 2.5 to 3 Earth radii from the pole of the dipole; recordings of the currents of the "solar wind" in interplanetary space were also made.

On September 12, 1959 a second spacecraft was launched toward the Moon. The weight of the unmanned station "Luna-2" after separation from the rocket was 390.2 kg. At 00 hrs. 02 min. and 24 sec. (Moscow time) on September 14, the "Luna-2" station reached the surface of the Moon. The last stage of the second spacecraft also reached the surface of the Moon, moving along a somewhat different trajectory.

For the first time in the history of mankind, a spacecraft fabricated by human hands had been launched from one celestial body to another. Pennants bearing the coat of arms of the USSR and the inscription "Union of Soviet Socialist Republics. September, 1959" were landed on the Moon.

The scientific instruments mounted on the "Luna-2" station permitted a number of important studies to be carried out along the path of the flight to the Moon and in the immediate vicinity of its surface. The magnetic measurements in the vicinity of the Moon showed that it lacks any significant magnetic field.

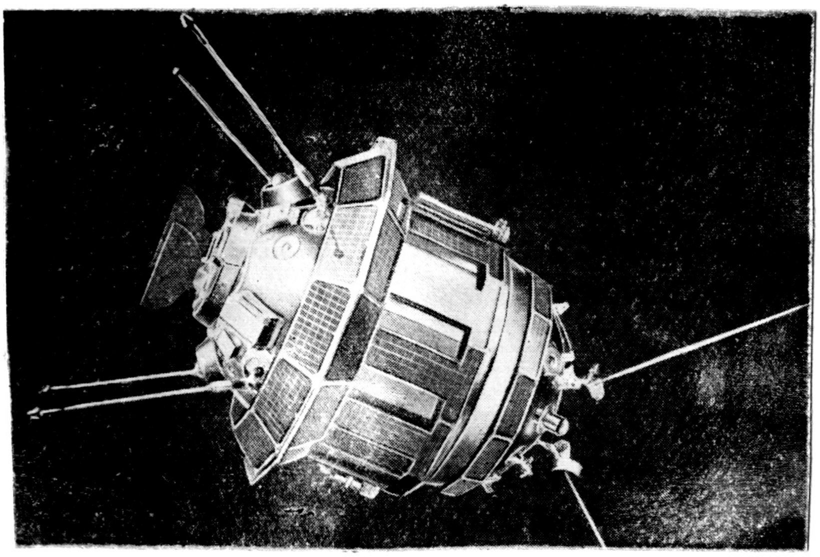
On October 4, 1959 a third spacecraft launched the unmanned interplanetary station "Luna-3" weighing 278.5 kg, into orbit around the Moon.

On October 7, the lens of the cameras of the station were aimed by a control system aboard the satellite toward the dark side of the Moon, which was photographed at two magnifications, and the pictures obtained were transmitted by television to the Earth. This flight was a clear demonstration of the ability of the new method of investigating large areas of the globe by means of rocket devices. It would have been impossible to investigate the side of the Moon which is invisible from the Earth by using any other methods. This accomplishment resulted in extremely important data regarding the side of the Moon which is not visible from the Earth. A new map of the back side of the Moon was prepared. It was found that it contained many more mountainous formations than plains. It was also observed that the density of the craters is greater than on the visible side. The results of the photographic study have appeared in the book "Atlas of the Dark Side of the Moon", published by the Academy of Sciences of the USSR, Moscow, 1960.

The first globe of the Moon was prepared on the basis of the materials contained in the Atlas. The most important of the newly discovered formations were named after outstanding individuals from all over the world.

The data from the investigation of the pictures transmitted by "Luna-3" aroused enormous interest in the scientific community, both here and abroad. /654

The flights to the Moon brought up a number of new problems regarding its investigation, which required the solution of a completely new technical problem: the soft landing of a spacecraft on the lunar surface.



Unmanned Interplanetary Station "Luna-3".

On April 2, 1963 a rocket was launched in the direction of the Moon; its final stage had at first been placed in a parking orbit like an artificial Earth satellite and then launched into the desired trajectory toward the Moon. On board this rocket was the unmanned station "Luna-4", weighing 1422 kg, which later separated from the final stage.

On April 6, the "Luna-4" station passed at a distance of 8500 km from the surface of the Moon and once again became an artificial Earth satellite traveling along an elongated orbit; later on, as a result of the powerful influences of the Sun and Moon, it became an artificial satellite of the Sun. During the flight, when "Luna-4" was located approximately 140,000 km from Earth, it was photographed at the Crimean Astrophysical Observatory.

The flight of the "Luna-4" provided experimental data which was important for further flights to the Moon and planets in the Solar System.

In 1965, the unmanned stations "Luna-5", "Luna-6", "Luna-7" and "Luna-8" were launched. All of these except "Luna-6" reached the surface of the Moon. All of them transmitted experimental data related to the technical problems involved in a flight to the Moon and elements of a soft landing on its surface.

The "Luna-8" automatic station was used to carry out a complicated test of the systems which would ensure a soft landing. The test showed normal operation of the systems at all stages of the landing on the Moon, except for the final one. Thus there remained only a final step to achieving a soft landing.

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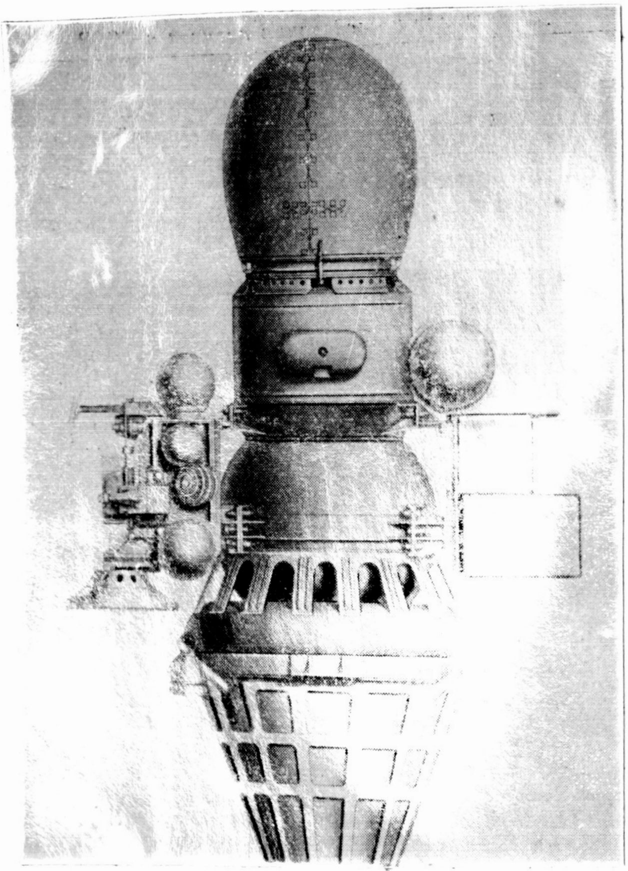
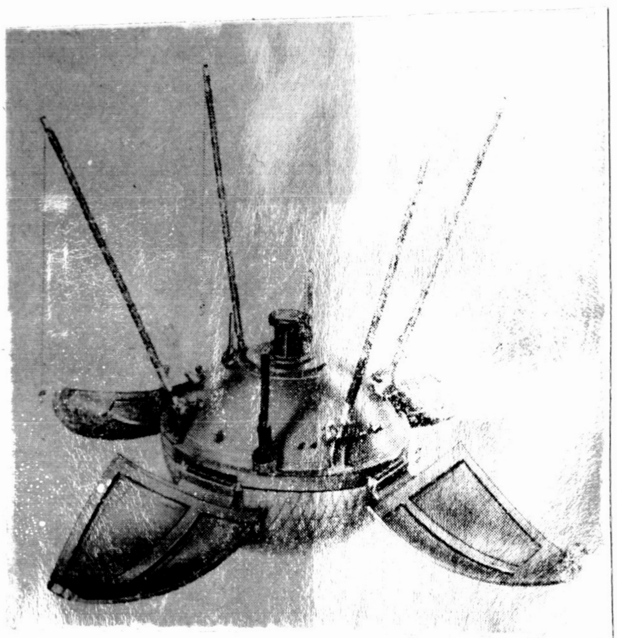


Rocket with Unmanned Station "Luna-9".



Unmanned Station "Luna-9 after Landing on the Moon.

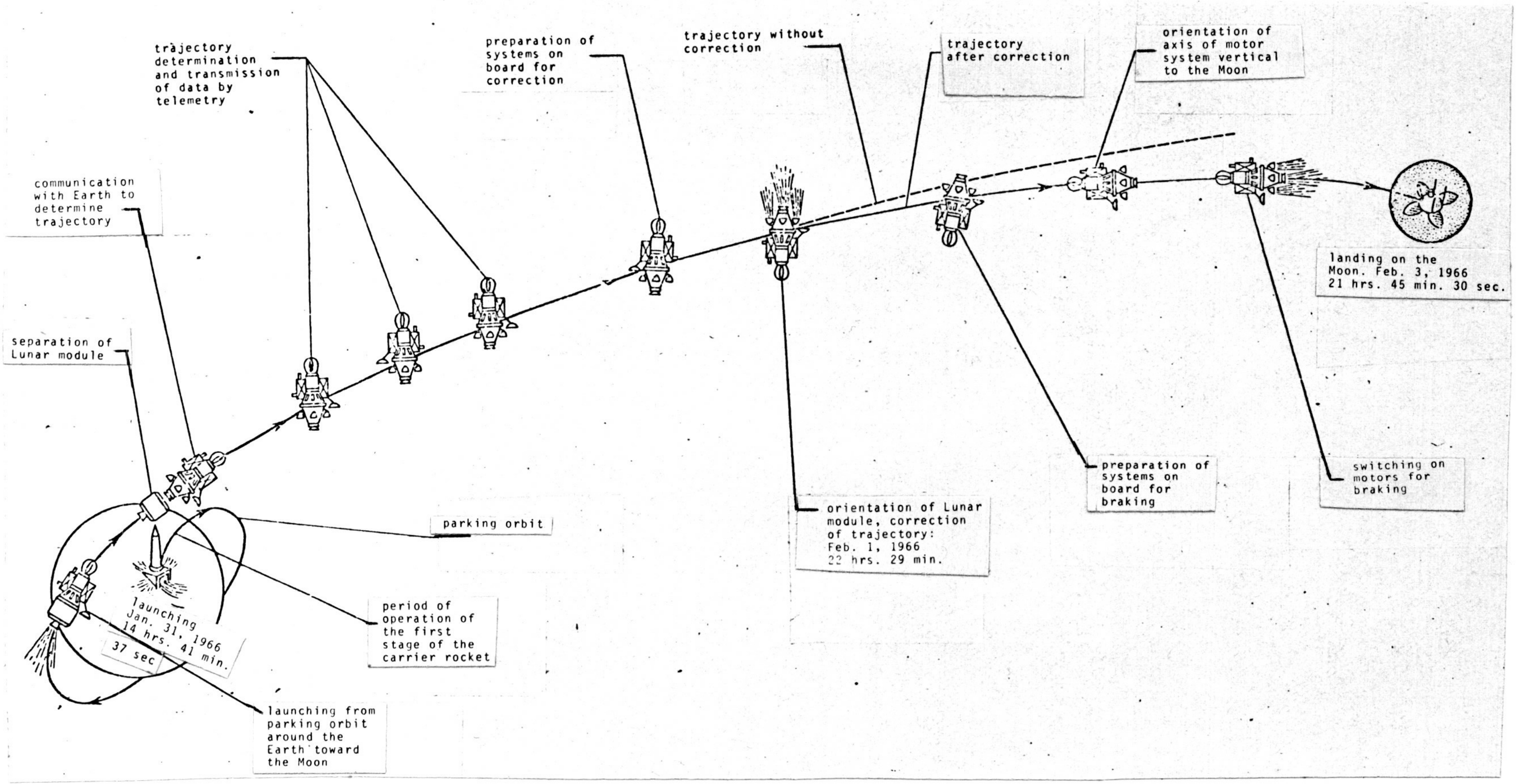
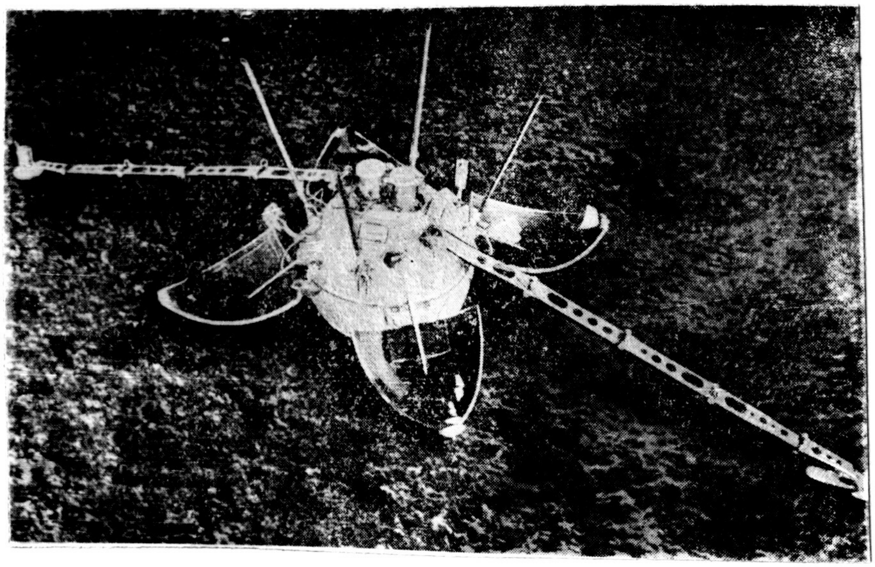


Diagram of the Flight of the Unmanned Station "Luna-9".

The unmanned station "Luna-9" which was launched on January 31, 1966, was the first vehicle to complete a successful soft landing on the Moon in the Sea of Storms in the vicinity of the Equator; this took place on February 3. The accomplishment of a soft landing on the Moon was a very important step in the development of astronautics and opened up tremendous possibilities for science and future exploration of space. /660



Unmanned Station "Luna-13" after Opening of Antenna Panels. At the Left: Extending Mechanism with Soil Probe-Penetrometer; At the Right: Radiation Densitometer with Transmitter.

After the "Luna-9" station had landed, a survey of the lunar landscape began with transmission of observations to Earth. The station transmitted a circular panorama of the lunar surface at different solar altitudes. For the first time man was able to gaze on a small portion of the lunar surface from close up, thus making it possible to carry out a number of important scientific estimates regarding the structure of the lunar surface. First of all, there was no dust on the lunar surface; in the second place its soil appeared sufficiently strong to support the weight of the station[2]. The pictures transmitted by the "Luna-9" station made it possible to distinguish details on the lunar landscape to within several millimeters.

On December 21, 1966 the unmanned station "Luna-13" was launched and later made a successful soft landing on the surface of the Moon,

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[2] The results of analysing the photographs transmitted by the "Luna-9" station were published in the book "First Panoramas of the Lunar Surface", Nauka Press, 1966.

also in the region of the Sea of Storms. The flight of the station lasted approximately 80 hours; during the flight, its trajectory was corrected so that it would land in the desired region of the Moon. At a distance of 70 km from the lunar surface, a system of braking motors was switched on and the "Luna-13" station slowed down and made a soft landing on the surface of the Moon. The "Luna-13" station also transmitted a lunar panorama to Earth. The data obtained with the "Luna-9" station were confirmed. In /661 addition a number of instruments (soil probe, dynamograph, and radiation densitometer) mounted onboard the "Luna-13" station carried out a number of direct measurements of the physical and mechanical properties of the lunar soil. Radiation in the vicinity of the lunar surface was also studied.

The flights to the Moon and the successful soft landings on its surface by spacecraft have provided a number of important items of information regarding our nearest neighbor in space.

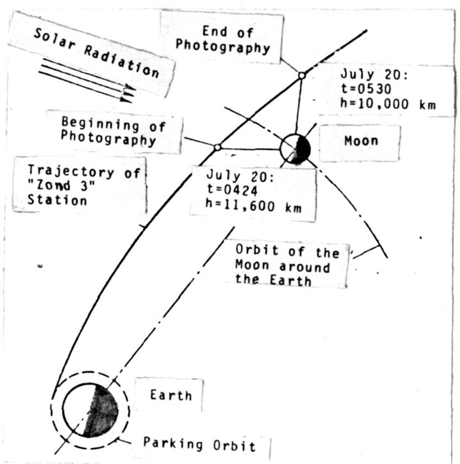

Diagram of the Path of the "Zond-3" Station Around the Moon While Making Photographs.

Following the flight of the unmanned station "Luna-3", which made the unique photographs of the side of the Moon which is **not visible** from Earth, it was necessary to complete the photographing of the lunar surface in order to obtain a complete map of it. This problem could be solved by carefully selecting a flight trajectory for a space probe, simultaneously solving a number of other problems of importance to making future interplanetary journeys.

On July 18, 1965 a rocket was launched carrying the unmanned station "Zond-3". The purpose of the launch was to test the systems of the station under conditions of prolonged spaceflight and to carry out scientific investigations in interplanetary space. The photographic and television system on board the "Zond-3" station were used to photograph the lunar surface including the part which is not visible from Earth and was not included in the pictures taken previously by "Luna-3". The pictures were taken from a distance of about 11,600 km, with illumination more favorable than that prevailing during the flight of "Luna-3". Transmission of the photographs to Earth took place from a distance of more than one million kilometers. The photographs received from the "Zond-3" station are distinguished by their high quality.

Almost no blank spaces were left on the hidden side of the

Moon after the flight of the "Zond-3". Hence, thanks to the pictures taken by the "Luna-3" and the "Zond-3" a practically complete picture of the entire lunar surface was available[3].

An important step in the continued exploration of the Moon was the design and launching of artificial satellites into an orbit around the Moon. The satellites opened up a wide perspective for a detailed investigation not only of the space in the vicinity of the Moon but also of the physical properties of the lunar surface: its chemical content, magnetism, gravitational field, and temperature.

On March 31, 1966 the unmanned station "Luna-10" was launched in the direction of the Moon. On April 3 it became the first artificial satellite of the Moon.

The scientific apparatus of the "Luna-10" station was intended to study the radiation hazards in the vicinity of the Moon, the gamma spectra received by the lunar surface, magnetic measurements, a study of its thermal properties and the density of micrometeorites in the vicinity of the Moon.

On August 24, 1966 the second artificial satellite, the unmanned station "Luna-11" was launched into orbit around the Moon; on October 22 a third was launched, the "Luna-12" station.

In addition to the scientific apparatus, the "Luna-12" station carried a photographic television apparatus for photographing individual portions of the lunar surface from a distance of about 100 km. /662

A study of the evolution of the orbits of the artificial lunar satellites provided important data for studying the gravitational field of the Moon. Thus, during the period from 1959 to 1966 outstanding successes were achieved in the study of the Moon and scientific data of the greatest significance were obtained.

An understanding of the secrets of the structure of the distant planets of the solar system, as well as flights to these planets (primarily Mars and Venus), have always been dear to the hearts of scientists.

Observations of the planets Mars and Venus have given rise to a number of interesting hypotheses regarding the possibility of life on them. However, the data obtained by terrestrial means are too sparse for any definite scientific conclusions to be drawn from them. The development of astronautical techniques in recent years has been so rapid that the problem of making a flight with

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[3] Results of analysing the photographs were published in the book "Atlas of the Dark Side of the Moon, Part II"; Moscow, Nauka Press, 1967.

unmanned stations to the distant planets became a technical reality.

On April 12, 1961, for the first time in history, an automatic interplanetary station ("Venus-1") was launched from the Soviet Union in the direction of the planet Venus. In the years that followed, a number of launchings to Mars and Venus were made.

On June 12, 1967 a Soviet unmanned station "Venus-4" was launched in the direction of Venus.

During these flights, on the one hand, the nature of cosmic space was investigated; on the other hand, the designs and systems of spacecraft were tested and many problems were solved regarding long distance radio communications and methods of controlling long flights of unmanned interplanetary stations.

The flights were made at times when the mutual positions of the Earth and Mars (or Venus) were most favorable. These periods occur approximately every 19 months for flights to Venus and every 25 months for flights to Mars.

All of the interplanetary unmannned satellites in the "Mars", "Venus" and "Zond" series were basically the same and one can gain an idea of all of them on the basis of the unmanned station "Venus-3".

As in the case of launching spacecraft toward the Moon, the last stage of the carrier rocket was first placed in a parking orbit around the Earth; later, rockets were fired to provide escape velocity in the desired direction. All of the unmanned interplanetary stations which were launched into deep interplanetary space weighed /663 approximately 1000 kg.

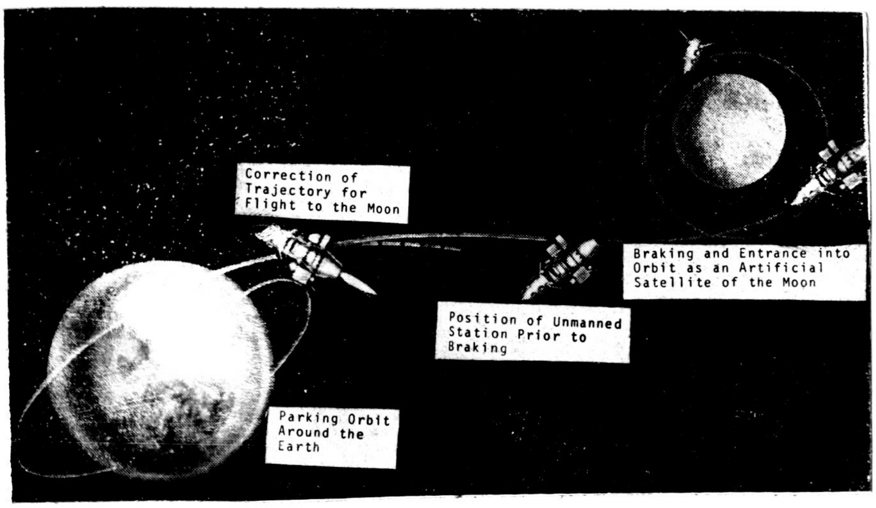
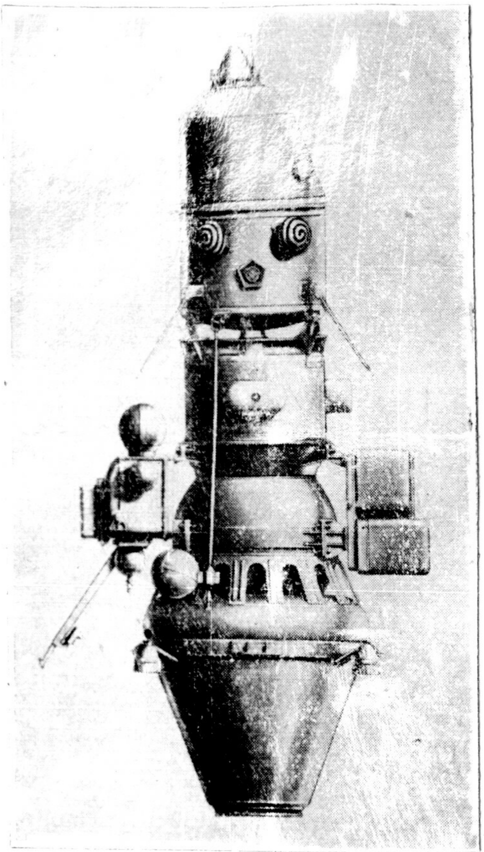


Diagram of the Flight of the Lunar Satellite "Luna-10".



Lunar Satellite "Luna-10".

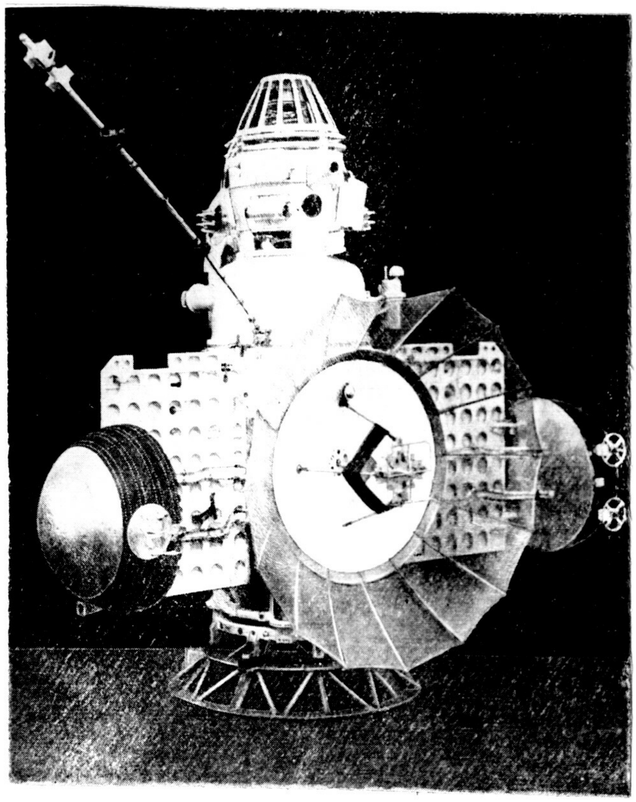
The flights of the unmanned stations into orbits around the planets Mars and Venus lasted many months and made it possible to test thoroughly the apparatus for automatic control of the stations. It should be mentioned that all during the flight it was necessary to keep the solar batteries oriented toward the Sun; this required the design of orientation apparatus which could operate for many months without interruption. Correction of the flight trajectory had to be so exact that the interplanetary unmanned station would pass near the planet with an error not exceeding the radius of the planet so that (in principle) the trajectory could be altered for landing on the planet. This meant that it was necessary to have on board extremely accurate systems for orientation, which take their bearings from the Sun and the star Canopus so that the unmanned interplanetary station could be placed in the desired angular position in space and the desired direction for the correction pulses for changing trajectory of the flight of the station could be given.

Radio communication with terrestrial points was accomplished both by means of nondirectional antennas and with a highly directional parabolic antenna; these made it possible to transmit to Earth a large amount of information during relatively short communication sessions. In order for the axis of the parabolic antenna to be aimed exactly at the Earth, a corresponding orientation system was used employing an optical and electronic apparatus which was able to orient the antenna to the Earth from different distances.

Even this brief discussion gives one an idea about the complex nature of the control system for directing the satellite.

It should also be added that the radio apparatus which kept track of changes in the trajectory, the radio link for giving commands and the radio link over which scientific data were transmitted to Earth were qualitatively new relative to similar systems used in launching the artificial Earth satellites and the spacecraft sent to the Moon.

Considerable material was obtained during the flights of the unmanned interplanetary stations "Venus-1", "Mars-1", Venus-2", "Venus-3", "Zond-1", "Zond-2" and "Zond-3". Interesting data were obtained regarding the interplanetary magnetic field, cosmic rays, interplanetary ionized plasma, long wave radiation, scattering of ultraviolet radiation, and micrometeoric particles. In particular streams of meteors were detected which had not previously been observed from Earth. /664



Unmanned Interplanetary Station "Venus-3".

In addition to the scientific data regarding cosmic space, a comprehensive experiment was carried out which tested the design, structure and flight control of similar unmanned interplanetary stations. The effectiveness of the entire complex of control devices used for flights into deep space, is clearly shown by the remarkable results obtained during the flight of the "Venus-3": the landing on the planet. This was the first time in human history that a spacecraft from one planet in the solar system had reached another planet.

In order to obtain some idea of the technical perfection required in the complex of instruments for controlling the flight of the "Venus-3" station, we must recall some of the data on this flight. During the flight, 31 communication sessions were held (16 dealt /665 with trajectory correction); in addition there were 1300 measurements of distance, more than 5000 measurements of radial components of flight speed, and approximately 7000 measurements of angular coordinates. All of this made it possible to get a direct and highly accurate idea of the actual trajectory of the flight. The measurements showed that regardless of the successful placing of the unmanned station on a flight trajectory to Venus, the error in aiming at the planet was 60,550 km from its center, which is about five times greater than the diameter of the planet. In order to enter a flight trajectory which would lead to landing on the planet, corrections in flight had to be made by means of a rocket motor (with the required orientation). This was accomplished when the station was 12,900,000 km from Earth. Measurements of the trajectory, made after the correction session, showed that the required flight speed had been attained with an accuracy within several cm/sec. After correction, the flight trajectory passed at a distance of 450 km from the center of the planet. Even if we take into account the error in determining the trajectory (less than 600 km) and the inexact value of the astronomical unit, which gives the additional error for a given flight of no more than 500 km, the mean square deviation from the calculated trajectory was better than 800 km. If we also take account of the fact that the tube of the trajectory (upon approach to the planet) is constricted by the action of the gravity of the planet (approximately twice for this flight) and that the radius of Venus is equal to 6100 km, we reach an error of 10-15 factors in the accuracy of the landing, which characterize this flight. During the flight of the unmanned station "Zond-2" plasma motors were used as the devices for controlling the orientation system.

The flights of the unmanned stations to the planets of the solar system have opened up for mankind broad horizons for direct investigation of their structure. We are making the transition from the era of theoretical hypotheses regarding the origin of the planets of the solar system to their experimental investigation by means of instruments landed on the planets or lowered to their surface.

After the building and launching of the first artificial Earth satellite, the flights of the lunar spacecraft, and the long distance spaceflights into interplanetary space as the result of which a tremendous scientific and technical experience was accumulated, Soviet scientists and engineers prepared for flights by man into cosmic space: the accomplishment of an age-old dream of mankind.

In order to make the first flight into space, it was first necessary to design and build a powerful carrier rocket capable of launching a spacecraft of the required weight into orbit around the Earth, and to build a spacecraft with complex apparatus for maintaining normal living conditions for man during the flight and apparatus for control and orientation of the space capsule in space; it was necessary to solve the problem of reentry for the capsule, entering the atmosphere at cosmic speed, and to build a system which would ensure a safe landing. Means had to be developed for reliable communications with the capsule and a ground control system for tracking the flight of the capsule. /666

The concentration of skilled labor made it possible to build a new three-stage carrier rocket and a "Vostok" space capsule in a short time. The "Vostok" carrier rocket consists of six rocket components: four lateral ones and one central one made up of a first and second stage, in which liquid rocket motors are mounted, and a third stage with its own motor. The peak power of the motors of the "Vostok" carrier rocket amounts to approximately 20 million horsepower. The total length of the rocket is 38 m, its diameter at the base is more than 10 m.

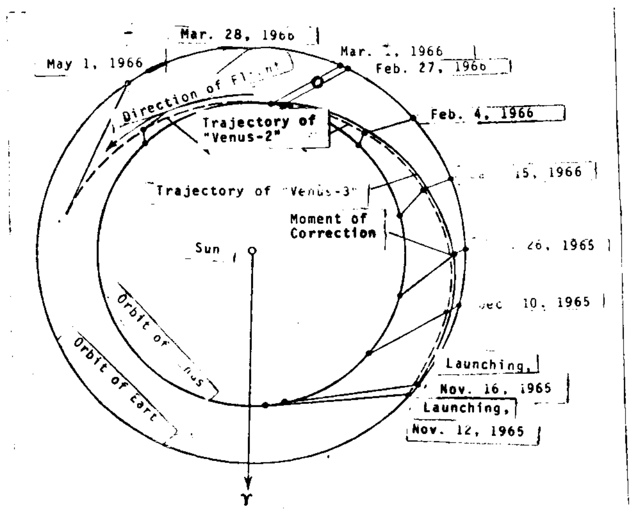


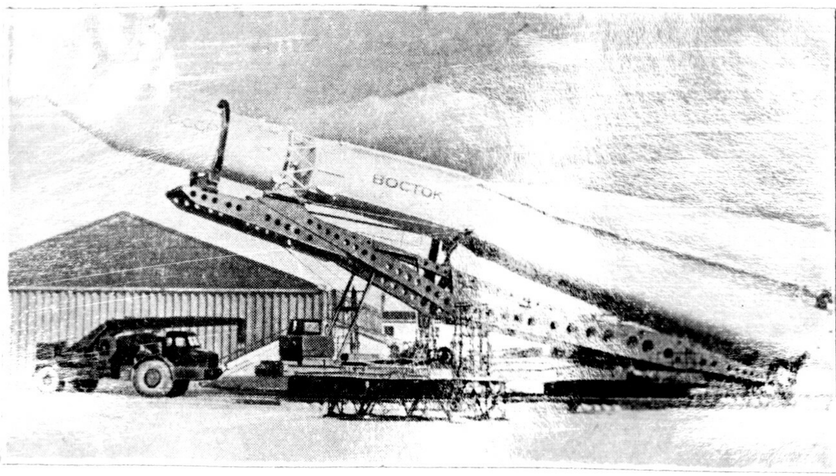
Diagram of the Flights of the Unmanned Interplanetary Stations "Venus-2" and "Venus-3".

Five experimental satellite capsules were built for testing and developing spacecraft in the years 1960-1961, with the goal of preparing for manned flights into space.

The first satellite capsule was launched into a planned orbit on May 15, 1960. All of the apparatus and control radial links for guiding the capsule operated normally. During the 64th orbit around the Earth, a command was given from Earth for switching on the braking rocket system. However, owing to a malfunction which occurred at this time in one of the guidance systems, the direction of the braking impulse was not the same as that which was intended so that the satellite could not be returned to Earth.

The second space capsule was launched into orbit on August 19, 1960. It was used for testing systems intended for keeping the cosmonaut alive. Aboard the capsule were two dogs named "Belka" and "Strelka", as well as other animals and biological materials. On the 18th revolution, the space capsule landed successfully in a chosen spot. The animals were ejected and landed in a container supported by a parachute. This was the first successful return of living organisms from space to Earth.

The third space capsule, launched into orbit on December 1,1960 was intended to repeat the program of the second space capsule. It carried two dogs, named "Pchelka" and "Mushka". After carrying out its program, due to a change in the launching trajectory from the /667



"Vostok" Carrier Rocket.

calculated one, the space capsule was destroyed when it reentered the dense layers of the atmosphere.

In addition to the testing of the systems onboard the spacecraft and studying the effects on biological materials both during flight and after landing, a broad program of scientific investigation was carried out on the space capsules, as a result of which the radiation danger for cosmic flights at heights up to 350 km was shown to be insignificant since there were no powerful solar radiations. It was also shown that the danger from meteorites was practically negligible.

Cabin of the Space Capsule "Vostok" After Landing.

The fourth and fifth space capsules, placed in orbit as satellites of the Earth on March 9 and 25, 1961, respectively, each made one revolution around the Earth. The flights of the fourth and fifth space capsules carried out the same program which was intended for use by the first flight of a spacecraft with a cosmonaut on board. These spacecraft carried in their cabins a dummy cosmonaut and several dogs. The dog on the fourth satellite was named "Chernushka" while the one on the fifth satellite was named "Zvezdochka". Both spacecraft landed safely on Earth in the desired region.

On April 12, 1961 at 0907 Moscow Time, the first cosmonaut Yu. A. Gagarin began his spaceflight on board the "Vostok-1". The spacecraft landed after making one revolution around the Earth. The first manned orbital flight in history had been accomplished. The spacecraft weighed 4725 kg. The effect of various factors of spaceflight on the human organism was investigated. For the first time man was subjected to a state of prolonged weightlessness, which lasted 55 min.

Man had entered a new era, the era of manned spaceflight.

Subsequent flights of Soviet cosmonauts were extremely important in clarifying the possibility of a prolonged stay of man in space. /668

The spacecraft "Vostok-2" piloted by cosmonaut G. S. Titov entered orbit on August 6, 1961 and made 17 revolutions around the Earth. The flight lasted 25 hrs. 18 min. G. S. Titov was able to work all during the flight. Some disturbances in the function of the vestibular apparatus of the cosmonaut were noticed.

The spacecraft "Vostok-3" piloted by cosmonaut A. G. Nikolayev, entered orbit on August 11, 1962, the flight lasted 94 hrs. and 22 min. More than 64 revolutions around the Earth were made. Within a few days the spacecraft "Vostok-4" piloted by cosmonaut P. R. Popovich was launched into orbit. His flight lasted 70 hrs. and 57 min; more than 48 revolutions around the Earth were completed. One of the most important results of this group flight of two spacecraft was a demonstration of the possibility of bringing the second spacecraft to the immediate vicinity of the first which will make it easier in the future to carry out maneuvers in approach and docking of spacecraft. In addition, it was also shown to be possible to have normal living conditions for man under conditions of prolonged spaceflight.

It should be mentioned that the first pictures of the cosmonauts in flight were transmitted via the Soviet television network and over the "Intertel" system and were seen in the majority of the countries of Europe.

The spacecraft "Vostok-5", piloted by cosmonaut V. F. Bykovskiy, was launched into orbit on June 14, 1963. His flight lasted 119.4 hrs. and he completed 82 revolutions around the Earth. Two days later on June 16, the spacecraft "Vostok-6" was launched, piloted by the first woman cosmonaut, V. V. Nikolayeva-Tereshkova. Her flight lasted 70.8 hrs. More than 48 revolutions around the Earth were completed. During this joint flight, the effect of various factors of cosmic flight on the human organism were tested including the organisms of men and women. The cosmonauts withstood their entry into orbit well, as they did their prolonged flight and return to Earth.

Interplanetary trips such as those to the Moon and Mars, for example, will never be made in a single-passenger capsule. Therefore the next stage was the building of a new multipassenger space capsule in the "Voskhod" series. The spacecraft had a device for a soft landing on the surface of the Earth, as well as a supplementary braking system which made it possible to make flights in still higher orbits than those of the "Vostok" type. The maximum height at apogee was 327 km and was accomplished during the flight of Yu. A. Gagarin. In the "Voskhod" capsule, the cosmonauts could fly without wearing their spacesuits and without any ejection system. In addition to the earlier orientation systems the spacecraft was fitted with a new system which used ion transmitters for directing the course. The entire spacecraft weighed 5320 kg.

The spacecraft "Voskhod-1" was launched into orbit as a satellite of the Earth on October 12, 1964 with a height at apogee of 409 km. Aboard the spacecraft was a crew consisting of the commander of the spacecraft, the cosmonaut V. M. Komarov, his scientific associate K. P. Feoktistov, and a physician, B. B. Yegorov. The flight lasted 24 hrs and 17 min. A broad program was carried out during the flight, testing a three-man piloted spacecraft. The ability to work together during the flight was tested with a group of cosmonauts. A number of physical, technical and scientific tests were also carried out in addition to extensive medical and biological tests which were made directly under conditions of prolonged space flight and with the participation of scientific and medical per- /669
sonnel. For the first time scientists were making observations and working in space.

On March 18, 1965 the spacecraft "Voskhod-2" was launched into orbit as a satellite of the Earth. It was piloted by a crew consisting of the commander, cosmonaut P. I. Belyayev, and his copilot, cosmonaut A. A. Leonov. During the second revolution of the flight, A. A. Leonov put on a spacesuit with an independent life sustaining system and went out through a special hatch to become the first man to leave a spacecraft directly in outer space. There he carried out successfully a number of tests and observations and returned sately to the spacecraft. The emergence of A. A. Leonov from the ship was observed on Earth by television. During the rest of the trip, tests were carried out of the operation of the systems of the ship, including medical, biological and other scientific investigations. After 26 hours and 17 revolutions around the Earth, the cosmonauts landed again using the soft landing system.

The emergence of man into outer space is an unprecedented experiment which showed that it is possible for man, not only to make flights into space, but to work actively in space itself. The solution of this problem is an important new stage in beginning studies of outer space. Wide opportunities have been opened up for carrying out work outside the spacecraft in space and consequently building scientific investigation laboratories there with exchange of crews and spacecraft for studying the planets of the solar system.

As we have pointed out above, an important factor in the spaceflights to other celestial bodies is the duration of the flights. To study the effects of prolonged exposure of the living organism to outer space, the "Cosmos-110" artificial Earth satellite was built to carry out extensive medical and biological tests.

The satellite was launched into orbit on February 22, 1966. It carried animals on board: two dogs named "Veterok" and "Ugolek". The orbit of the satellite was selected so that its apogee was 904 km, in other words, much higher than for the spacecraft "Vostok" and "Voskhod". Thus as it moved, the "Cosmos-110" satellite came directly into the region of the radiation belt of the Earth. The duration of the flight of the satellite "Cosmos-110" was 22 hrs, at the end of which time the satellite made a soft landing on the Earth, so that all of the apparatus and experimental animals were recovered. This interesting experiment provided invaluable data regarding one of the most important problems of space physiology, the effect of conditions of cosmic flight on the state of the nervous reflex regulation of the cardiovascular system. It was found that the conditions of spaceflight cause certain changes in the water, salt and albumin exchange in the motor system of animals.

Following the flights of the spacecraft "Vostok" and "Voskhod" in the Soviet Union, on April 23, 1967 the first experimental launching of a new type of spacecraft "Soyuz-1" piloted by cosmonaut V. M. Komarov was carried out. It was Komarov who earlier made the flight as a member of the crew of the "Voskhod-1". The purpose of the flight of the "Soyuz-1" was to test a new type of spacecraft, the operation of the systems, and elements of the design of the capsule under conditions of spaceflight while carrying out both scientific and technical, as well as medical and biological investigations. During the period of the test flight, V. M. Komarov was able to carry out completely his program on board the "Soyuz-1" spacecraft. At the end of the flight of the "Soyuz-1" spacecraft, the famous cosmonaut V. M. Komarov tragically lost his life. The contribution made by V. M. Komarov will always go down in the his- /670
torical annals of the exploration and investigation of space.

The flights of the artificial Earth satellites, the launchings of the spacecraft toward the Moon, Mars and Venus, the flights of the first spacecraft and their return to Earth, the accomplishment of the first spaceflight of man in history and the emergence of man into outer space have marked the arrival of an era of exploration of the universe. Ten years have passed since the moment when the first artificial celestial body was built, the first Soviet artificial Earth satellite. During this extremely short period of time, the world has witnessed a number of extremely important scientific and technical achievements which not long ago were still in the realm of fantasy.

Soviet Cosmonauts (from left to right): V. M. Komarov, K.P. Feoktistov, Yu.A. Gagarin, A. A. Leonov, G.S. Titov, V.F. Bykovskiy, V.V. Nikolayeva-Tereshkova, P.R. Popovich, P.I. Belyayev, B.B. Yegorov and A.G. Nikolayev.

In our time, science and technology are developing faster and faster each year. The technology of spaceflight is developing particularly intensely. Space vehicles of different types will see ever increasing usage for solving various scientific and related problems.

The time has come for the actual accomplishment of projects which previously seemed fantastic: the time for building extraterrestrial scientific stations and the spaceflights of man to the Moon, Mars, Venus and other planets of the solar system.

The solution of such enormous problems requires an enormous effort of collective labor, the further development of many fields of theoretical and experimental science and of many branches of technology. This now involves a tremendous amount of scientific material caused by the scientific revolution in our concepts of the physics of the space around the Earth, the interplanetary medium and in a number of very important fields of astronomy and astrophysics.

In the following we shall consider the most important scientific data which have been obtained by various space devices.

The first determinations of the density of the upper layers of the atmosphere by means of artificial Earth satellites were carried out in 1957-1958 as a result of investigating changes of their orbits due to aerodynamic braking. In addition the third Soviet artificial satellite carried a manometer which made it possible to obtain data on the density of the air over a wide range of altitudes. Both of these methods were later developed considerably thus making it possible to obtain a considerable amount of experimental data. This method permits obtaining data regarding density averaged over certain regions near the perigee of the satellite during several successive orbits; however this measures not only the density ρ but also the value $\rho\sqrt{H}$, where H is the scale of the altitudes. Manometric measurements make it possible to obtain numerous values of density but with considerable error. Therefore the overall agreement between the density values obtained by the two methods still appeared insufficient. In addition to these two basic methods, others were used. Thus in 1958, e.g., Soviet scientists determined the density at a height of 430 km on the basis of measuring the rate of diffusion of an artificial sodium cloud. /671

Nevertheless the information which has been obtained thus far has made it possible to get a rather clear idea regarding the upper atmosphere and different variations of its structural parameters: density, pressure and temperature. Five basic types of variation in density at heights of 180 km and above have been distinguished: diurnal variations, variations with changes in solar activity, semiannual variations, variations caused by magnetic activity, and latitudinal variations. All of these with the exceptions of the variations caused by the magnetic activity and possibly the semiannual variations are related to the irregularity of energy accumulation in the upper atmosphere resembling the form of ultraviolet radiation.

The regularities and the amount of energy received during the day leads to a sharp variation in the temperature of the upper atmosphere. The ratio of the maximum diurnal temperature and the minimal nocturnal temperature in the thermosphere reaches about 30%. Consequently the density varies by 1.5-2 times at heights of about 200 km and 5-8 times at heights of 500-600 km. However, the specific nature of the change in density with time of day has not yet found an adequate explanation; several investigators have suggested as its explanation, a supplementary heat source while others think it is possible that it can be explained by the effect of ionization drift into neutral components of the atmosphere.

Variations with changes in solar activity can be divided into two classes: (a) variations with the pattern of the solar cycle, caused by changes in the total flux of solar ultraviolet radiation with the 11-year cycle, and (b) variations related to short-term increases in the flux of the ultraviolet radiation, e.g., during several rotations of the Sun around its axis. Since measurements of the flux of solar ultraviolet radiation are rare, the usual index for this value is the flux from the Sun on the 10.7 cm radio wavelengths. It is found that the relationship between the temperature in the thermosphere and the radiational flux on the 10.7 cm wavelengths is not the same. The reaction of the upper atmosphere to variations in the ultraviolet radiational flux from the Sun (on the basis of measurements of the 10.7 cm radio emission) with the pattern of the solar cycle is twice as strong as to the short term variation. The reason for this discrepancy apparently is that the flux of the ultraviolet solar radiation, as the 10.7 cm radiation flux, has two components: one from the entire solar disk and the other from the active regions. There are indications that the spectral content differs for these components of the ultraviolet radiation.

The semiannual variations are global with maxima in April and October and with minima in January and July. Their causes are probably related to the ionized component of the upper atmosphere in the Northern and Southern Hemispheres with pronounced lines of geomagnetic fields. Investigation of the variations caused by the geomagnetic activity presents a very difficult problem: they are not continuous with time and their observation requires precise /672 determinations of the orbital elements of the artificial Earth satellites during relatively short time intervals. An increase in temperature takes place several hours after the beginning of geomagnetic perturbation, and somewhat earlier at higher latitudes near the polar aurorae. The relationship between the magnitude of the magnetic activity and the heating of the atmosphere is apparently nonlinear: the relative value of the reaction of the atmosphere is great during small perturbations.

The latitudinal variation in density is small; the increase in density from the equator to high latitudes amounts to about 30% at heights of several hundred kilometers. There are indications of an increase in density in the zone of the polar aurorae, which is apparently related to the braking of particles of the polar aurorae.

A much less investigated problem is that of the composition of the upper atmosphere, particularly its variations. A majority of the measurements of the composition have been made with rockets rather than satellites. Two methods have been used: the mass spectrometric method and that involving the absorption of ultra violet radiation from the Sun. Even the earliest rocket experiments showed that at heights of 100-120 km, a diffuse separation of gases begins. The existence of a diffuse separation at heights greater than 120 km was confirmed also in subsequent measurements of concentrations at different atmospheric components.

At heights of 200-250 km the principle components of the atmosphere remains N_2; the relative concentration of atomic oxygen O, which has formed during dissociation of molecular oxygen by solar ultraviolet radiation, increases. The amount of molecular oxygen decreases with height. Beginning at 250-300 km, the principle component of the atmosphere is atomic oxygen.

Still higher, beginning at altitudes of 500-600 km, in years of minimum solar activity at heights of 1000-1500 km in years of minimum activity, the atmosphere becomes helium-hydrogen. The layer with helium in the form of a principle component appears apparently only in years of maximum solar activity. The very outermost region of the Earth's atmosphere consists of atomic hydrogen. Its concentration up to distances of several Earth radii has been measured on the basis of its scattering of solar L_α-radiation during the flight of the Soviet space station, particularly "Zond-2".

If all the principle components of the atmosphere (N_2, O_2, O) are found in a state of diffuse distribution in the atmosphere and their concentrates decrease with an increase in solar activity so that the temperature decreases as well, the behavior of hydrogen is quite different; its concentration apparently changes not at all with changes in the solar cycle. This is connected with the fact that hydrogen diffuses easily out of the Earth's atmosphere and its dissipation increases sharply with an increase in temperature.

Very little is known regarding the seasonal diurnal and latitudinal variations of the composition. This is explained by the inadequacy of sufficient data, and also by experimental difficulties which are encountered in mass spectrometric measurements. The measurements on the satellite "Explorer-17" showed the existence of considerable variations in concentration at altitudes of 260-700 km but no regular variations were determined. There are indications of an increase in the O concentration during the night time and an increase in the relative concentration of O at high latitudes.

The construction of artificial satellites has made it possible to obtain important new data regarding the ionosphere of the Earth, particularly its external portion above the maximum of the F layer. The first Soviet artificial satellites carried devices for measuring the ionosphere at high altitudes; the first Soviet artificial Earth satellite was able to sketch a profile of the electron concentration up to altitudes on the order of 1000 km.

It was found that the rate of decrease in concentration with /673 height above the maximum of the F layer is very low. Measurement of the electron concentration at altitudes up to 20,000 km, performed by Soviet space rockets in 1959, supported the findings of a high electron concentration at these heights, obtained earlier on the basis of whistling atmospherics. Subsequent experiments showed that the ionosphere of the Earth extends at least out to five Earth radii and probably further.

The layers of the ionosphere are not so sharply defined as was previously supposed; today we usually talk not about layers but about the D, D, F_1, F_2 regions. Rockets and satellites have measured the ion composition of these regions. The principle components of the *D* region of the ionosphere are apparently the complex ions H_3O^+ and $H_5O_2^+$. O_2 and NO predominate in the *E* region. In the *F* region, there is a gradual transition from these ions to O^+ ions. Still higher up, the principle components of the ionosphere are He^+ and H^+ ions. A layer with a predominance of He^+ appears at altitudes of 800 km and more only in years of high solar activity. The outer ionosphere consists practically of individual protons, while He^+ is a small component.

Data are available on latitudinal variations of ionospheric composition; to a certain extent they also indicate an increase in the amount of O^+ relative to H^+ toward higher latitudes.

Metal ions of Mg^+ and other substances were observed at altitudes of ~ 100 km during the flights of Soviet geophysical rockets. Studies of the wind at these altitudes have shown that sporadic E_s layers are observed usually in the vicinity of the maximum gradients of wind movements. Electrical fields, which arise in the corresponding structures of the wind fields, cause the long-lived metal ions to gather in a narrow region of altitudes (on the order of several kilometers) to form the sporadic E_s layer.

Considerable information regarding the behavior of the ionosphere above a maximum electron concentration has been obtained with radio sounding from high-flying satellites. The distribution of electron concentration over the entire Earth has been measured; its dependence upon time of day, latitude, etc., has been determined. These data made it possible to establish that the majority of anomalies in the *F* layer can be explained on the basis of the concept of ionization drift, which leads to a latitudinal shift in the maxima of electron concentration during the day.

As suggested earlier, satellites and rockets have found that the electron temperature during the daytime is much greater than the ion temperature as a result of energy exchange between photoelectrons which are formed by the ionization of atmospheric components by solar ultraviolet radiation, and by ionospheric electrons. However, this excess, although it decreases in value, is also observed during the night. The ion temperature varies between the temperature of the neutral component and the electron temperature, although this variation is quite irregular. In the outer ionosphere, the ions temperature increases and approaches the electron temperature, which increases with distance from Earth. At distances on the order of five Earth radii, at which the drop in the electron and ion concentrations stops, the temperature in the ionosphere amounts to about 10-20 thousand degrees. Data indicate that at great distances the concentration of hot plasma amounts to 30-50 cm^{-3}; however, various methods give contradictory results.

The discovery of the radiation belt of the Earth was completely unexpected, although various theoretical investigations dealing with the motion of particles of cosmic rays in the field of a geomagnetic dipole, indicated a class of quasiperiodic trajectories for charged particles, close to the trajectories of the particles in the radiation belt.

The particles captured by the geomagnetic belt were recorded by the first Soviet and American satellites, but a correct interpretation of the measurements was obtained only after detailed analysis. Several years and a great many experiments were required before a reliable theory regarding the structure of the radiation belt could be developed. The apparatus used in the first satellites was designed to record cosmic rays. The first idea regarding the two belts of captured radiation ("inner" and "outer") turned out to be both a consequence of poor selectivity of the transmitters as well as the impossibility of an unambiguous interpretation of their readings; this led to an inaccurate estimate of the particle fluxes. The construction of diverse apparatus with good spectral characteristics and the launchings of satellites with a wide range of orbital parameters made it possible to obtain the required data for studying the general structure of the radiation belt. /674

The discovery of the radiation belt of the Earth stimulated a great many theoretical investigations devoted to the investigation of the motion of charged particles in magnetic fields. Expermental data have supported a number of theoretical views regarding the motion of charged particles in the magnetic field closely resembling a dipole. In turn, the theoretical ideas (in particular, the introduction of a natural system of geomagnetic coordinates) (B, L)[4], have made it possible to accumulate highly diverse experimental materials which have made it possible to explain a number of the regularities in the formation of the radiation belt of the Earth.

In the absence of electrical fields, a particle moves so that B at the point of reflection and L during its longitudinal drift coincide. In the external regions of the geomagnetic field, deformed by the solar plasma, this system of coordinates (B, L) describes the particle distribution poorly, and it is necessary to introduce a third coordinate (the local time, e.g.). Electrons and protons of different energies fill the entire region of the geomagnetic trap, and at the present time there are no data which pertain to the deviation from electrical neutrality. The energy spectrum of both electrons and protons is lower on the average as we move toward the more remote envelopes, although deviations are observed.

The proton fluxes in the region with $L < 2$ are quite stable; there is no foundation for saying that there is a significant variability in the electron fluxes in this region with the exclusion of low altitudes. In the outer belt, the particle fluxes vary con-

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[4] B equals density of the magnetic field at a given point; L equals geocentric distance of a line of force at the equator, expressed in Earth radii.

siderably; the variations increase with distance from the Earth. Particularly high variations occur during magnetic storms, when the electron fluxes vary by several orders; during the principle phase of the storm there is a sharp increase in electron fluxes with energies of tens of keV, while electron fluxes with energies of hundreds of keV and more decrease; large low-energy proton fluxes also appear, after which there is a return to the picture preceding the storm; at first, however, the fluxes of high-energy electrons are greater than before the storm. Twenty-seven-day variations of electron fluxes have been detected. The most interesting phenomenon in the radiation belt is the zone of low-energy protons (with energies of hundreds of keV and less). This zone is obviously responsible for the formation of a ring current in the principle phase of the geomagnetic storm, whose existence was previously predicted on the basis of an analysis of geomagnetic data. However, the data on this phenomenon are still very scarce; we do not know the spectrum of the low-energy portion of these protons (order of tens of keV); the long-term structure of this zone has not been investigated; /675
the mechanism for injecting these particles into the magnetosphere has not been explained.

Numerous experiments have been carried out in the zone of the polar aurorae. Low-energy electrons (one of the principle agents producing the polar aurorae) were first recorded by the third Soviet artificial satellite. The polar aurorae are a rapidly changing phenomenon, and several of their investigations were carried out more suitably from rockets than from artificial satellites. Detailed investigations were conducted of the electrons entering the upper atmosphere and forming the very beautiful and shifting forms of the polar aurorae; the spectrum of these electrons usually has a sharply pronounced maximum at an energy of about 5 keV, but more complex spectra are also found. The low-energy protons have been poorly investigated; they are responsible for the formation of the less bright, prolonged forms of polar aurorae. Their energy spectrum, estimated on the basis of terrestrial observations, is similar to the energy spectrum of the protons in the zone where the solar plasma flows around the magnetosphere of the Earth. Apparently the protons in the polar aurorae play an important role in the energy balance and in the supply of hydrogen to the upper atmosphere in the higher latitudes.

The processes occuring in the radiation belt of the Earth, the mechanisms of the introduction of particles into the geomagnetic trap, their acceleration, the shift to other drifting envelopes, the interactions with the electromagnetic radiation have all been only slightly investigated at the present time. For these investigations, it is insufficient to have even highly detailed measurements of all the related phenomena in separate satellites. It is necessary to build a special system of satellites since the measurements on a single satellite do not make it possible to differentiate the variations in time from variations in distance, and to investigate the processes taking place in different parts of the magnetosphere.

Nevertheless, it is possible to define and partially explain a number of phenomena. First of all, the lifetimes of particles in different magnetic envelopes have been measured. This has been done by diverse means, in particular, by measurements of the flux of effluvient particles in the region of the South Atlantic anomaly, by measurements of the rate of decay of the intensity of artificially injected particles, etc. At low altitudes, the losses of particles are satisfactorily explained by scattering in the upper atmosphere of the Earth. The rate of particle loss at high altitudes has not been explained conclusively, although the majority of authors agree that the cause is scattering of the pitch angles of the particles owing to their interaction with electromagnetic waves. Several investigators state that the particle concentration in the radiation belt is determined by the equilililibrium between the number of particles and the electromagnetic radiation, generated by the instability of anisotropic fluxes of particles in the magnetic field.

The problem of injection of particles and their acceleration is a much more complex one. The shortness of their lifetimes and the rapid variations of intensity in the radiation belt show that the mechanism of the neutron albedo cannot cause the intensity which is observed, with the possible exclusion of hard protons in the inner belt. We have already mentioned that the spectrum becomes more complex as we move toward the inner magnetic envelopes; this is one of the arguments for a mechanism of betatron acceleration. The variations in the intensity of the electrons in the outer belt during magnetic storms may be (at least partially) explained by adiabatic processes, although both non-adiabatic losses and particle acceleration are observed.

One of the possible mechanisms for introduction of particles into the magnetosphere is the breakdown of particles of the solar wind by neutral currents of the geomagnetic field at high altitudes. Recently, some experimental data have been obtained supporting this theory. Another possible mechanism (diffusion through the limit /676 of the magnetosphere) has also been inadequately investigated, although several estimates indicate the possibility of a higher diffusion rate than was supposed previously. It is interesting to mention in this regard the appearance of low-energy protons in the outer magnetic envelopes (coinciding in time with polar sub-storms). It is also not impossible that the penetration of particles into the zone of the polar aurorae and the magnetosphere takes place from a reservoir of particles existing on the night side beyond the limit of capture. Measurements above the zones of the polar aurorae indicate that the capture of particles along the geomagnetic lines of force is possible even with an intense emission of particles into the atmosphere. We must assume that further investigation of the motion of particles using a system of satellites in the outer envelopes, in the vicinity of the neutral points and a neutral magnetic field of the tail of the Earth, will make it possible to explain the problem of the mechanisms of capture and acceleration of particles in the geomagnetic field.

Prior to the appearance of space technology, the investigations of the external sources of the geomagnetic field were complicated, since they could not be localized by means of terrestrial measurements. In addition, from the investigation of the geomagnetic variations it was necessary to conclude that there were at least two external sources of the field: currents in the ionosphere, producing the diurnal variations of the geomagnetic field and the polar substorms, and a ring current (located at somewhat greater distances) related to the principle phase of the geomagnetic storm. Support for the existence of currents in the ionosphere at altitudes in the vicinity of 100 km was provided by the flights of geophysical rockets, which detected jumps in the amplitude of the geomagnetic field when intersecting the proposed current layer.

A ring current at a distance of about three Earth radii had been observed previously during the flights of the first Soviet lunar rockets and had been ascribed to the above-mentioned belt of low-energy protons. The annular current, as well as the proton belts, have still been only slightly investigated; the measurements were made from a small number of satellites. There are indications, however, that it shows definite asymmetry and that the growth of the ring current followed the pattern of the magnetic storm.

Prior to the beginning of space exploration, it was suggested that the geomagnetic field extends to considerable distances (possibly even hundreds of thousands of kilometers) and its compression takes place only because of encounters with isolated solar corpuscular currents. The flights of spacecraft and satellites with high apogees showed that the plasma flux from the Sun (or "solar wind") is a constant phenomenon and the limitation of the magnetosphere to the diurnal side by the plasma currents is also constant. The geomagnetic field forms a cavity in the plasma flux - the magnetosphere. The limit of the magnetosphere on the day side is shifted by a distance of about 10 Earth radii, while on the morning and evening sides it is shifted by a distance of about 14 radii; these values change depending on the pressure of the solar wind. This pressure leads to the displacement of the lines of force which emerge from the polar cap into the "tail" of the magnetosphere. The tail of the magnetosphere is a characteristic structure consisting of two force tubes, corresponding to the two polar caps and separated by a flat neutral layer in which the force of the field is close to zero. The lines of force in the tail are approximately parallel in the direction of the Sun. The diameter of the tail amounts to about 40 Earth radii; its length is unknown, but exceeds 80 Earth radii. In any case, signs of the tail have been detected at a distance of six million kilometers (about 1000 Earth radii).

Artificial satellites also make it possible to carry out a more detailed investigation of the true magnetic field of the Earth, carrying out magnetic recordings much more rapidly and over a much greater portion of the Earth's surface than has previously been achieved with terrestrial recording. /677

Cosmic rays are an important means for investigating many properties of interstellar and interplanetary media, the sources of their generation, radiation from physical processes taking place in the centers of stars, and in defining new laws regarding the structure of matter. Soviet artificial satellites and spacecraft have carried out a broad program of investigating primary cosmic rays, their chemical composition, and variations of their energy spectrum over a wide energy range.

A great many satellites in the "Cosmos" series have been launched to investigate variations in cosmic rays. The "Electron" satellites permitted investigation of long-term variations in the nuclear components of primary cosmic rays and made it possible to follow the variations of different groups of nuclei depending on solar activity.

A comparison of the measurements carried out on board spacecraft and satellites during the period of maximum solar activity (1959-1960), with measurements made during a minimum of solar activity, indicate an increase in the fluxes of the two groups of nuclei by 1.7-2 times. For heavy nuclei with a charge $Z \geq 15$, such a comparison with appropriate statistical reliability was carried out first. The correlation between the generation of the nuclei of solar cosmic rays and chromospheric prominences was studied, particularly for the group of neucli with charge $Z \geq 15$. Important results were obtained on board the "Proton" space stations. As a result of the measurements, it was possible to measure the energy spectrum of all particles and protons within the energy range from $3 \cdot 10^{10}$-$1.5 \cdot 10^{14}$ eV.

A comparison of the energy spectrum of all the particles (protons and multicharged nuclei) and the energy spectrum of protons shows that in a region where the energy of the primary particles is 10^{10}-10^{12} eV, these spectra are similar in the first approximation. At energies above $\sim 10^{12}$ eV, as the energy increases, the intensity of the protons apparently decreases much more rapidly than the intensity of all the particles.

An analysis of the data obtained on the heavy "Proton" satellites shows that there is a definite increase in the effective cross section of protons with carbon nuclei in the energy range from $2 \cdot 10^{10}$ to $5 \cdot 10^{11}$eV. Data have been obtained on the composition of heavy nuclei in primary cosmic rays.

Measurements of the cosmic rays in their variations at great distances from Earth were carried out on board the lunar spacecraft and unmanned stations "Mars", "Venus", and "Zond". These measurements made it possible to detect the relationship of the 11-year cycle of intensity of primary cosmic radiation to the radial gradient of the intensity of cosmic rays. During the years of maximum solar activity, the radial gradient of the intensity of the cosmic rays is about 5% for one astronomical unit. The very same change in intensity of the cosmic rays depending on the distance from the Sun does not occur simultaneously. This clearly indicates a complex relationship between the cosmic rays and globs of solar plasma and the magnetic field frozen in the plasma.

Theories regarding the constant plasma current emerging from the Sun were based on observations of comets and several other theoretical works; the first flights of Soviet rockets to the Moon made it possible to detect the currents of charged particles. Different apparatus is now being used to investigate these particles; much of it allows the fine characteristics of the propagation of these particles to be studied in terms of their speeds.

A considerable amount of data has already been obtained on the properties of the interplanetary plasma. The heating of the material of the solar corona by means not yet understood leads to a gradual acceleration of the plasma to supersonic speeds. At some distance from the Earth, the speed of the quiet current amounts /678 to about 300 km/sec, increasing to 500-800 km/sec in the perturbed regions of the current; the concentration of charged particles in it varies within limits of 0.3-100 particles/cm^3.

The plasma flux evokes a magnetic field at the perimeter of the Sun; the Sun's rotation on its axis causes the lines of force of this field to take on the shape of an Archimedes spiral in the plane of the ecliptic. Usually, this field has a sectoral structure; in some sectors, the field is oriented toward the Sun, while in others it is oriented away from the Sun. Within each sector, the components of the plasma vary in a certain manner. Various inhomogeneities are superimposed on this regular picture: it serves as a background on which complex phenomena are superimposed: the passage of shock waves, the collision of a faster current with a slower one, etc. A significant field component is observed in the perpendicular ecliptic of the direction.

There is still inadequate data dealing with the composition of the interplanetary plasma. All measurements of positive ions have been made by means of electrostatic analyzers, so that there was no reliable division of the ions. An analysis of the energy spectrum and the angular characteristics of the propagation of the particles has made it possible to distinguish with a high level of reliability at least the protons and the α-particles as well. There are preliminary indications of the existence of He^+ ions in the current, although this figure has turned out to be unexpectedly high and does not agree with the existing concepts regarding the nature of the ionized equilibrium in the solar corona and the interplanetary medium. It is not impossible that ions which have initially been identified as He^+ may turn out to be heavier elements.

The temperature of the ions is determined on the basis of the energy spectrum and the angular characteristics of the currents; it varies within very wide limits: from $6 \cdot 10^3$ to 10^6 °K. Determination of the temperature is not completely reliable, since the high energy "tail" of particles does not follow Maxwellian distribution. An isotropy of the temperature appears to be usual; along the direction of the magnetic field, the temperature is approximately 2.5 times greater than in the perpendicular direction. This temperature ratio is determined by the interaction of particles with a magnetic field and the inhomogeneity of the interplanetary plasma and may possibly be related to the mechanisms of plasma heating. Measurements of the neutral component in the interplanetary medium are very difficult. During the flights of Soviet interplanetary probes, measurements have been made of the average concentration of neutral hydrogen on the basis of the solar radiation scattered by it in the L_α line. There are very few measurements available for electrons in the interplanetary medium.

The rate of the plasma flow is greater than the speed of propagation of perturbations in it; hence, a shock wave is formed when the flow passes through the magnetosphere of the Earth. The existence of a shock wave was predicted by Soviet scientists and later detected with the satellites. The distance between the shock wave and the limit of the magnetosphere at any given point amounts to 2-4 Earth radii. At the front of the shock waves, there is a thermolysis of the particles, and particles of much higher energies appear than in the interplanetary medium. The specific collective processes which lead to deformation of a shock wave are unknown, although an examination of the mechanism suggests a complex and variable picture. Regardless of the considerable volume obtained, study of the interplanetary plasma in its interaction with the planets is still only in the initial stages.

One of the important questions facing us is the problem of the manner in which the flux energy is transmitted to the magnetosphere of the Earth. Correlations have been detected between the speed of the solar wind and the magnetic activity on Earth, and between the force of the magnetic field in the interplanetary medium and the magnetic activity; magnetic disturbances usually take place in those cases when the magnetic field in the transitional region between the shock wave and the magnetosphere is directed toward /679 the south. It is difficult to decide at the present time which of two mechanisms for introducing energy to the magnetosphere (injection of particles or heating of magnetospheric plasma) is the predominant one. Therefore it is very important to carry out some long-term measurements in different regions of cosmic space: in the interplanetary medium, in the magnetosphere, and simultaneously by means of terrestrial methods.

More extensive possibilities opened up for astronomers when it became possible to put instruments beyond the limits of the dense atmosphere and to carry out ultraviolet and x-ray studies of the Sun and other sources. The solar spectrum in the ultraviolet range contains many emission lines of highly ionized elements; the majority of these lines are known. The intensity of the line L_α H I, the line λ 304 Å He II and several others vary depending on solar activity; However, these variations are not as great as was previously supposed. The x-ray spectrum of the Sun has been studied; the intensity and nature of the x-ray spectrum varies considerably with the pattern of the solar cycle and with the increase of individual active regions on the Sun. A study of the short-wave spectrum of the Sun and its variations is of considerable importance not only for solar physics but for geophysics as well, inasmuch as this radiation is a principle source of energy reaching the upper atmosphere of the Earth. Therefore the most important problem now is the organization of a cosmic survey of the Sun, which would ensure the observation of a great many phenomena related to solar activity.

Spacecraft launched toward the Moon, Mars, and Venus have already brought back much interesting data and have begun the process of direct investigation of the planets.

The soft landing of spacecraft on the lunar surface has laid the foundation for a study of the mechanical properties and microstructure of the lunar soil. The hardness of the lunar terrain is apparently rather high, no less than several kilograms per square centimeter. The "Luna-10" spacecraft carried a multichannel analyzer of γ-radiation. The results of its measurements showed that the lunar rocks closely resemble basalt with a low content of radioactive elements.

Measurements of the magnetic field of the Moon were begun with the flight of the Soviet spacecraft "Luna-2". Further studies of the magnetic field in the vicinity of the Moon were carried out by the "Luna-10" and confirm the initial findings regarding the absence of a significant amount of magnetism on the Moon.

We are living in an era of rapid progress in science and technology. Along with the use of atomic energy for peaceful purposes, the development of quantum electronics, molecular biology, and a number of other fields of science, space exploration belongs to those fields of knowledge which are opening up for mankind, great vistas of scientific knowledge and the conquest of nature.

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Research Translation Division (151)
Acton, Massachusetts
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